US011549068B2

(12) United States Patent
Petty

(10) **Patent No.: US 11,549,068 B2**
(45) **Date of Patent: Jan. 10, 2023**

(54) **ULTRASONIC DEGASSING OF HYDROCARBON PRODUCTION FLUID**

(71) Applicant: **CONOCOPHILLIPS COMPANY**, Houston, TX (US)

(72) Inventor: **Brian Colt Petty**, Midland, TX (US)

(73) Assignee: **CONOCOPHILLIPS COMPANY**, Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **17/032,894**

(22) Filed: **Sep. 25, 2020**

(65) **Prior Publication Data**

US 2021/0009906 A1 Jan. 14, 2021

Related U.S. Application Data

(63) Continuation of application No. 15/978,477, filed on May 14, 2018, now Pat. No. 10,787,617.

(51) **Int. Cl.**
C10G 32/00 (2006.01)
B01D 19/00 (2006.01)
C10G 53/02 (2006.01)

(52) **U.S. Cl.**
CPC ***C10G 32/00*** (2013.01); ***B01D 19/0078*** (2013.01); ***C10G 53/02*** (2013.01)

(58) **Field of Classification Search**
CPC C10G 32/00; C10G 53/02; B01D 19/0078
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,560,914 A	2/1971	Webb
4,682,308 A	7/1987	Chung
4,805,156 A	2/1989	Attali et al.
5,641,228 A	6/1997	Prokopenko
6,666,095 B2	12/2003	Thomas et al.
7,697,375 B2	4/2010	Reiderman et al.
10,392,926 B2	8/2019	Huang et al.

(Continued)

FOREIGN PATENT DOCUMENTS

GB	2420510 *	5/2006
GB	2420510 A	5/2006

OTHER PUBLICATIONS

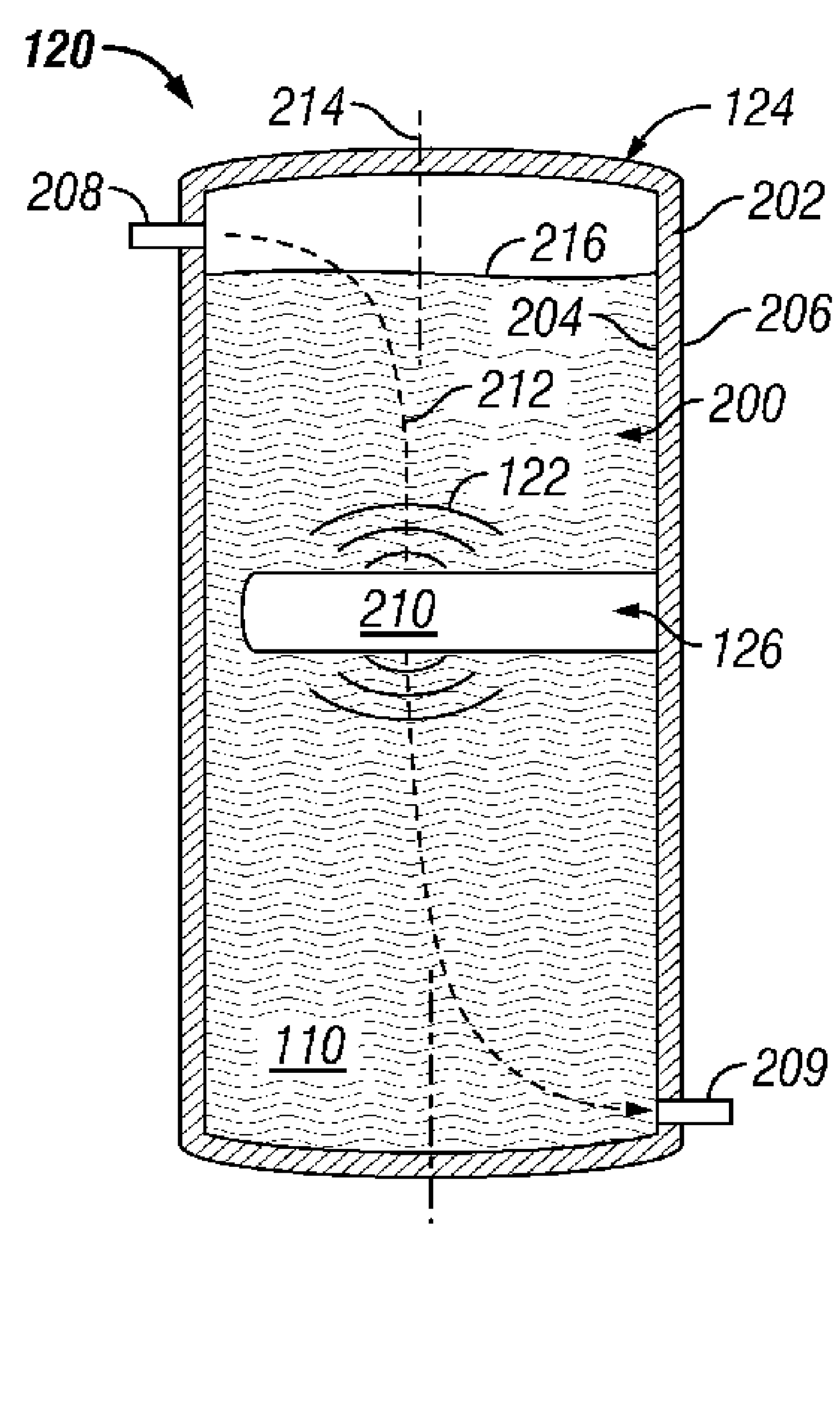
Schmidt, D. et al.; "New Technologies for Safe and Cost Effective Oil Conditioning in North Dakota" Status report to the North Dakota Oil & Gas Research Program, Final Report; Jun. 1, 2017; pp. 1-49.

Primary Examiner — Randy Boyer
Assistant Examiner — Juan C Valencia
(74) *Attorney, Agent, or Firm* — Polsinelli PC

(57) **ABSTRACT**

Provided are embodiments that include a hydrocarbon fluid processing system including an ultrasonic hydrocarbon degassing unit including a vapor recovery vessel adapted to direct flow of a hydrocarbon fluid mixture along a flowpath extending through an interior of the vapor recovery vessel, and an ultrasonic transducer system disposed inside the vapor recovery vessel and in the flowpath of the hydrocarbon fluid mixture. The hydrocarbon fluid mixture including a hydrocarbon liquid and a gas entrained in the hydrocarbon liquid, the ultrasonic transducer system adapted to transmit ultrasonic signals into the hydrocarbon fluid mixture along the flowpath, and the ultrasonic signals adapted to separate the gas from the hydrocarbon liquid.

18 Claims, 10 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

2005/0115405	A1*	6/2005	Yamada	B01D 19/0078 95/30
2010/0011867	A1	1/2010	Van Klooster et al.	
2013/0167654	A1	7/2013	Ueberschlag et al.	
2013/0192386	A1	8/2013	Ueberschlag et al.	
2016/0023244	A1	1/2016	Zhuang et al.	
2019/0101423	A1	4/2019	Ueberschlag et al.	
2019/0345396	A1	11/2019	Petty	

* cited by examiner

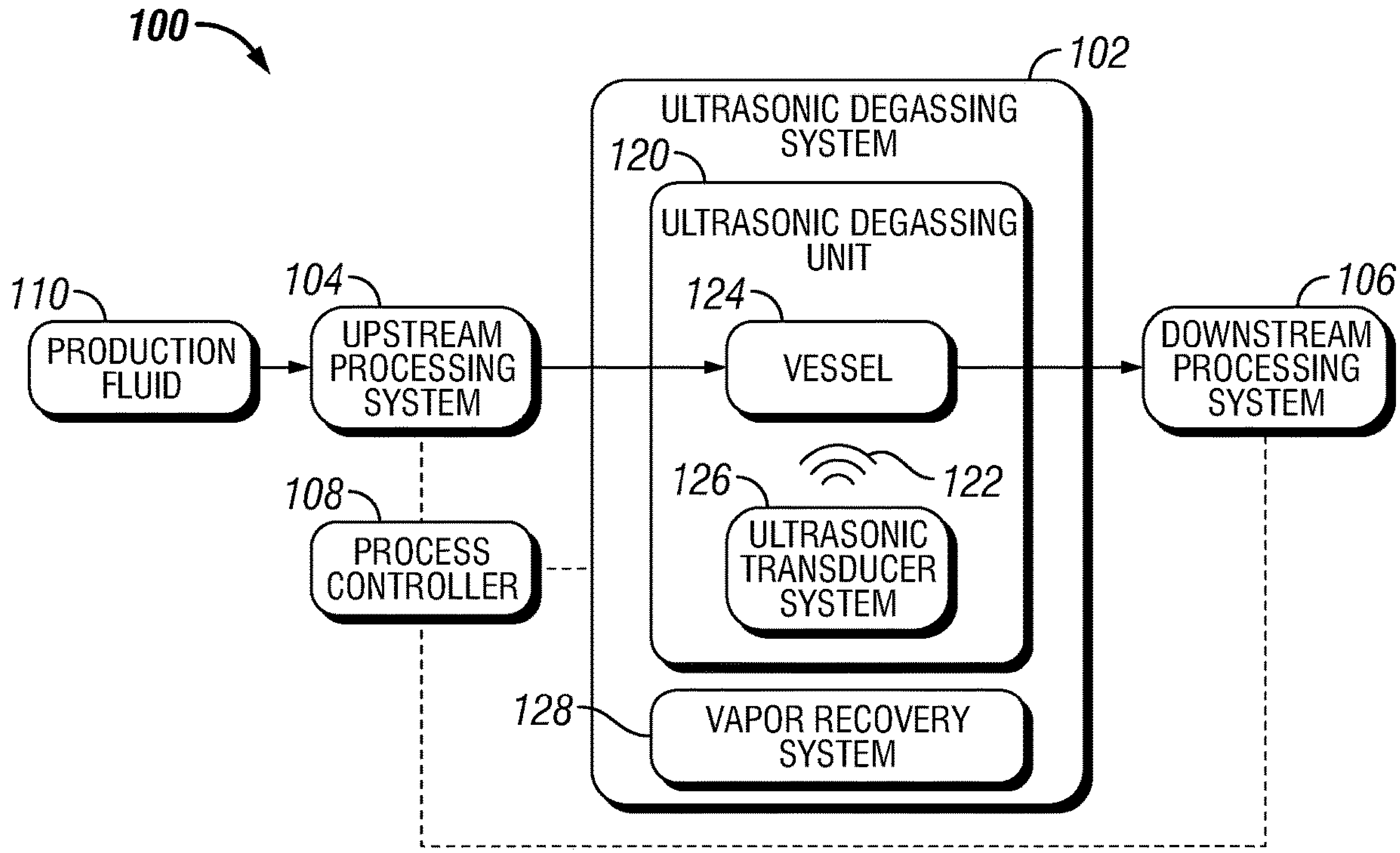

100
102
ULTRASONIC DEGASSING SYSTEM
120
ULTRASONIC DEGASSING UNIT
124
VESSEL
110
PRODUCTION FLUID
104
UPSTREAM PROCESSING SYSTEM
106
DOWNSTREAM PROCESSING SYSTEM
126
122
108
PROCESS CONTROLLER
ULTRASONIC TRANSDUCER SYSTEM
128
VAPOR RECOVERY SYSTEM

FIG. 1

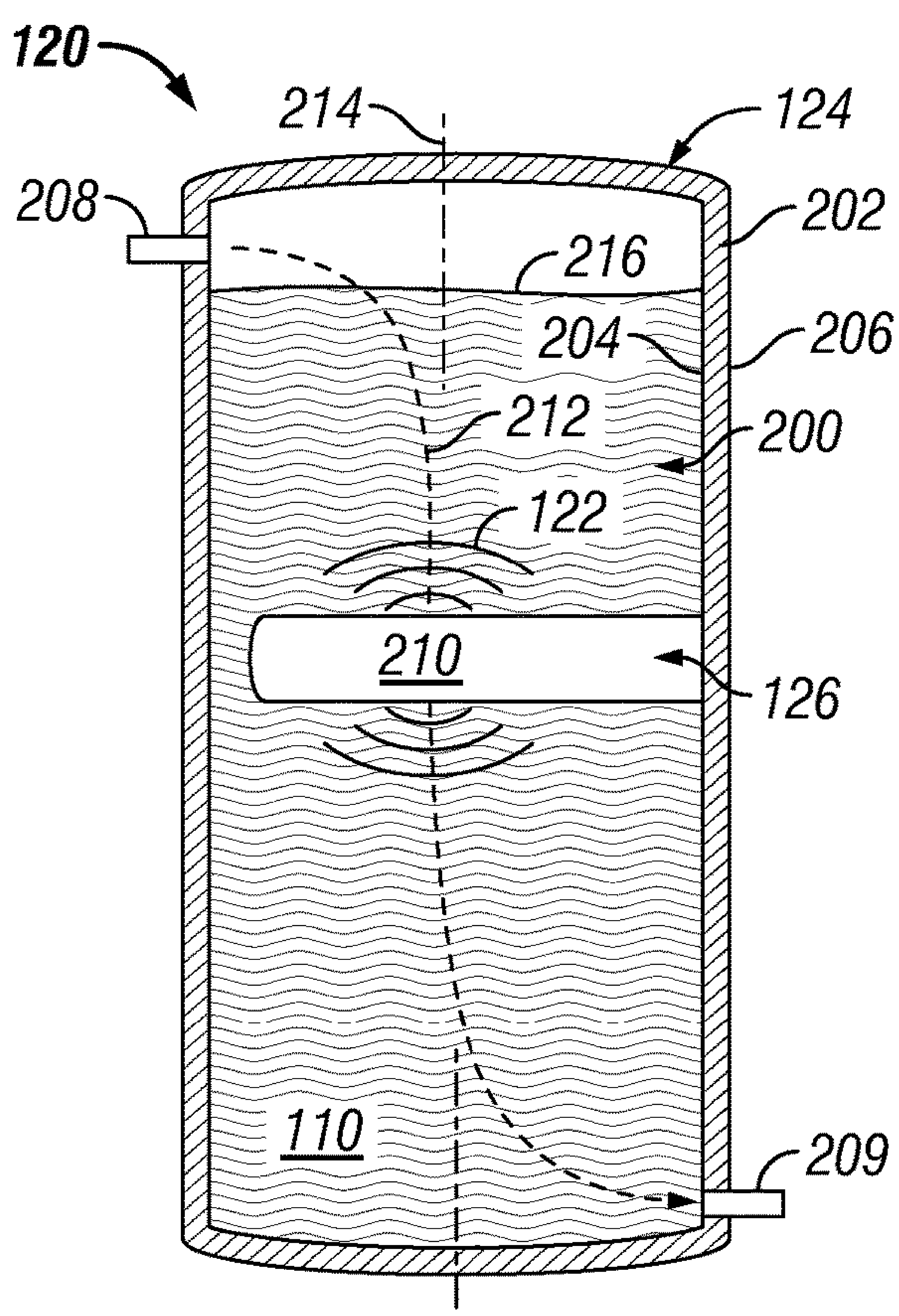

120
214
124
208
202
216
204
206
212
200
122
210
126
110
209

FIG. 2

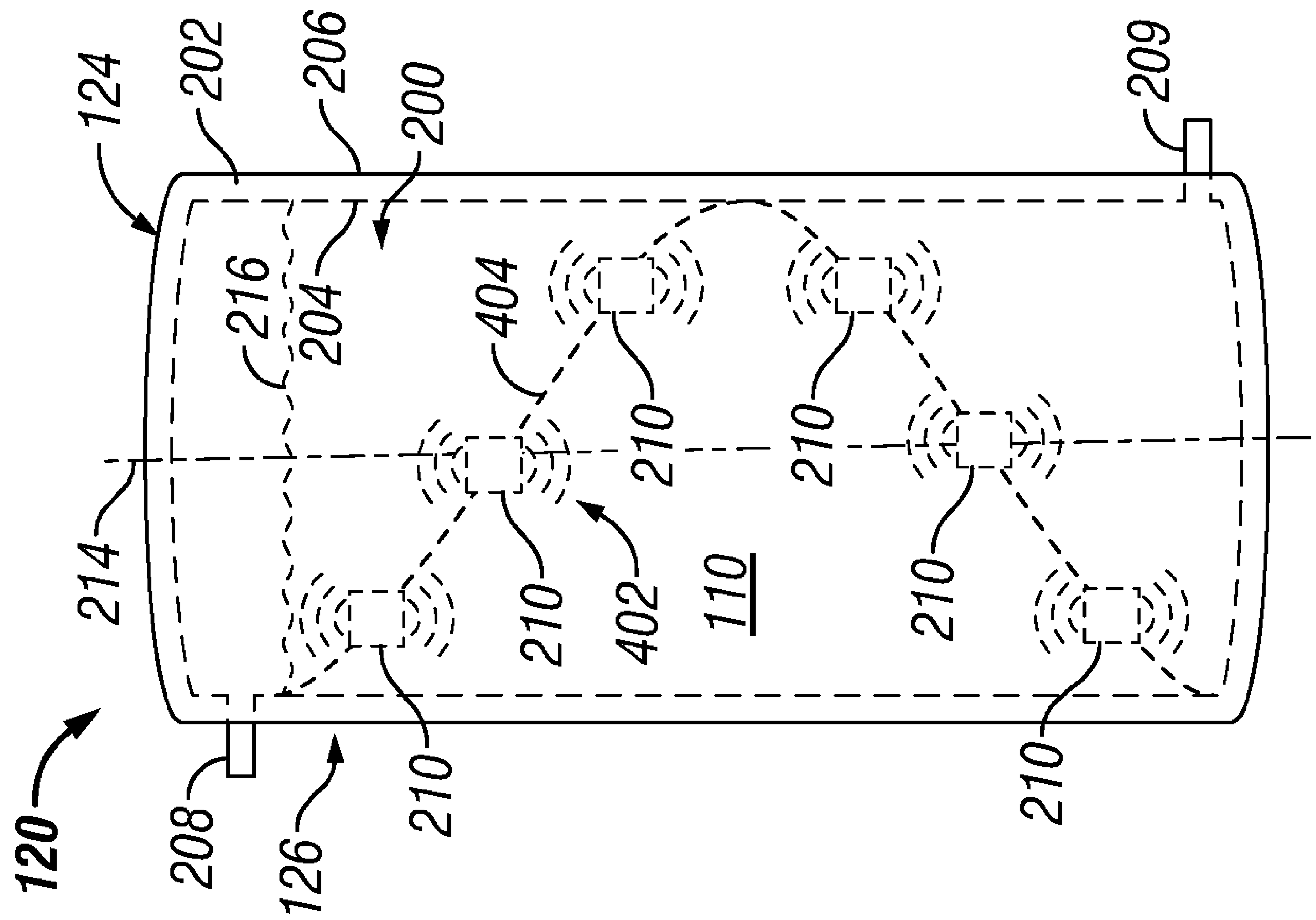

120
124
202
206
200
209
216
204
404
214
210
402
110
208
126

FIG. 4

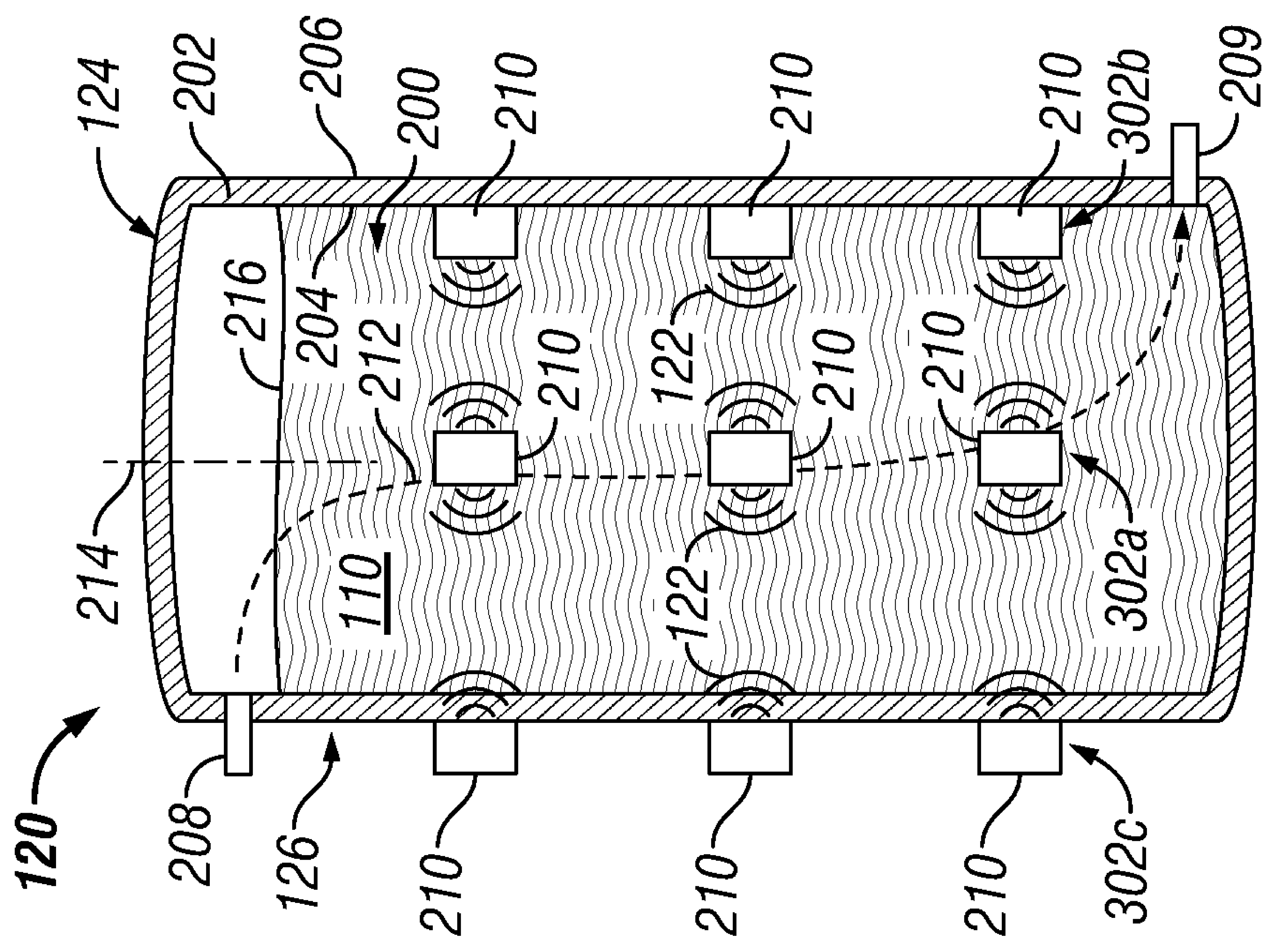

120
124
202
206
200
210
302b
209
216
204
212
122
214
110
302a
208
126
302c

FIG. 3

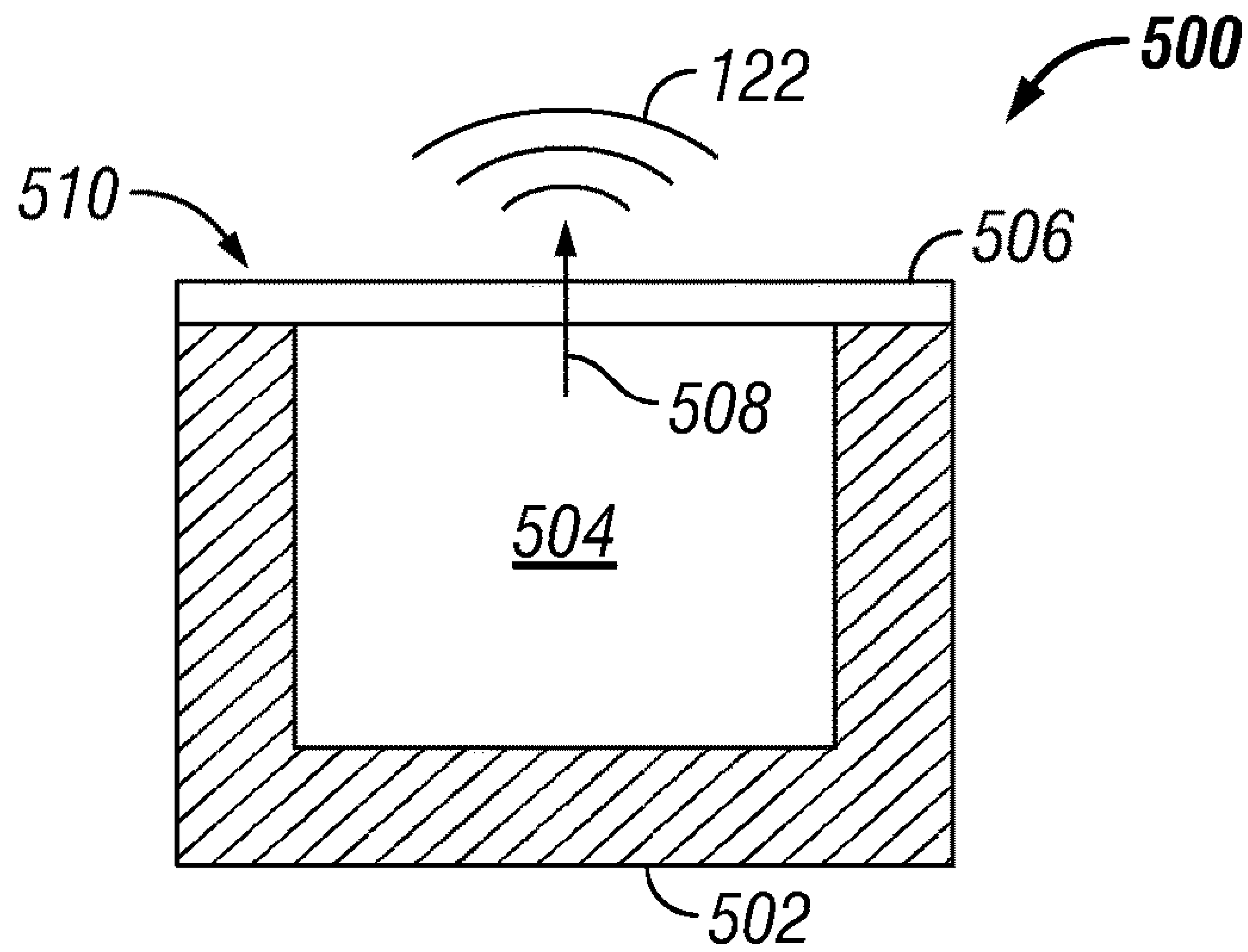

500
122
510
506
508
504
502

FIG. 5

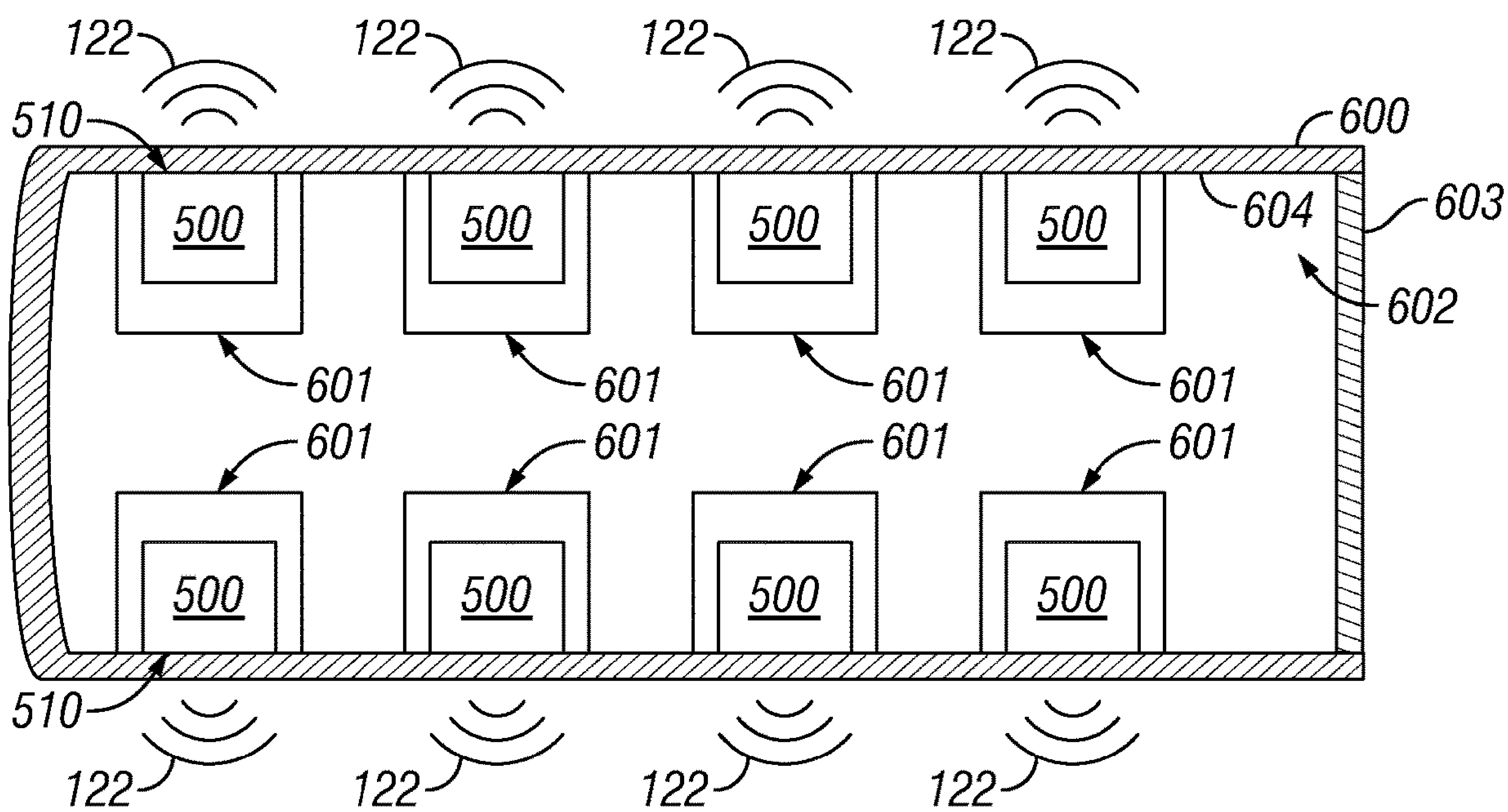

122
122
122
122
510
600
500
500
500
500
604
603
602
601
601
601
601
601
601
601
601
500
500
500
500
510
122
122
122
122

FIG. 6

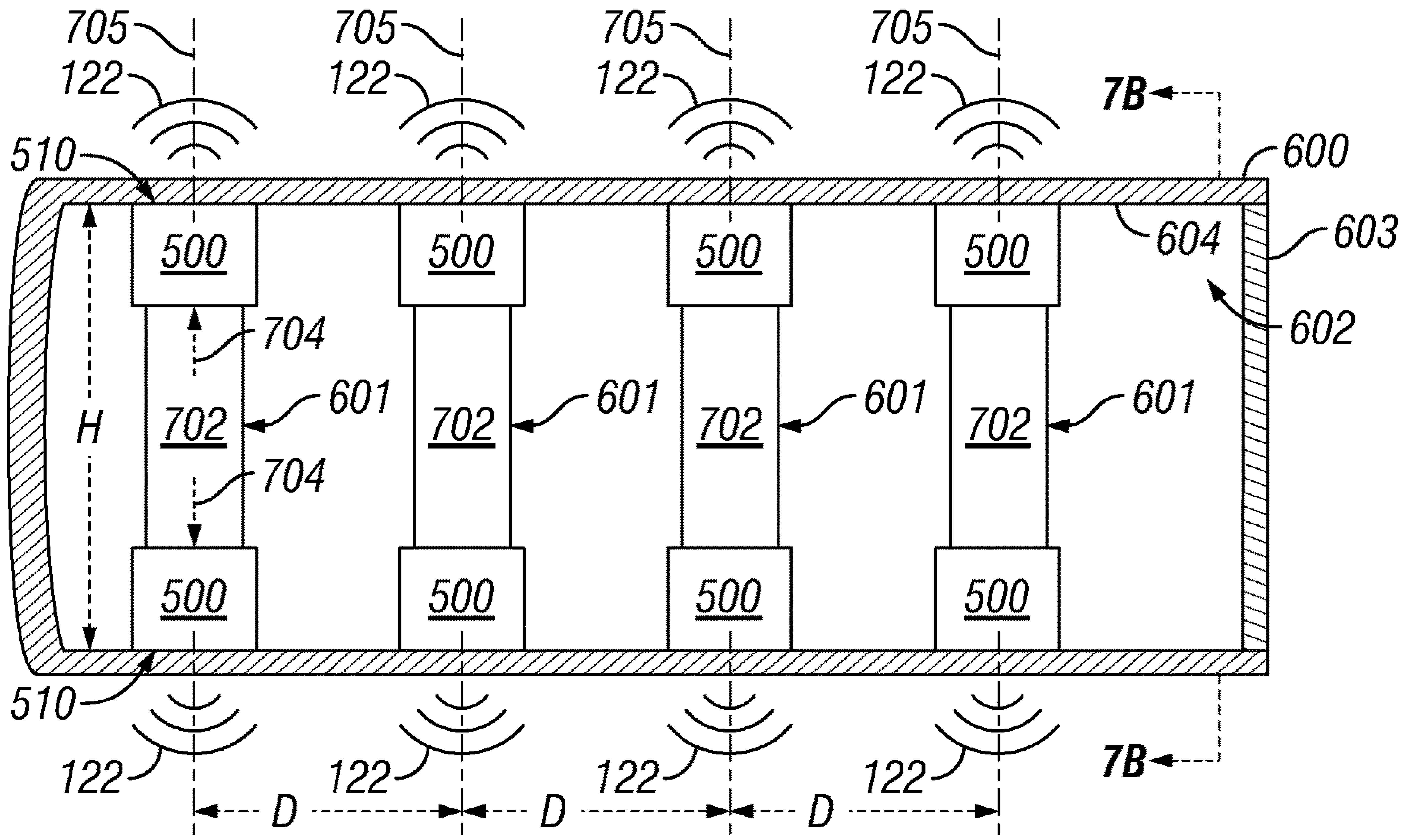

705
705
705
705
122
122
122
122
7B
510
600
500
500
500
500
604
603
602
704
H
702
601
702
601
702
601
702
601
704
500
500
500
500
510
122
122
122
122
7B
D
D
D

FIG. 7A

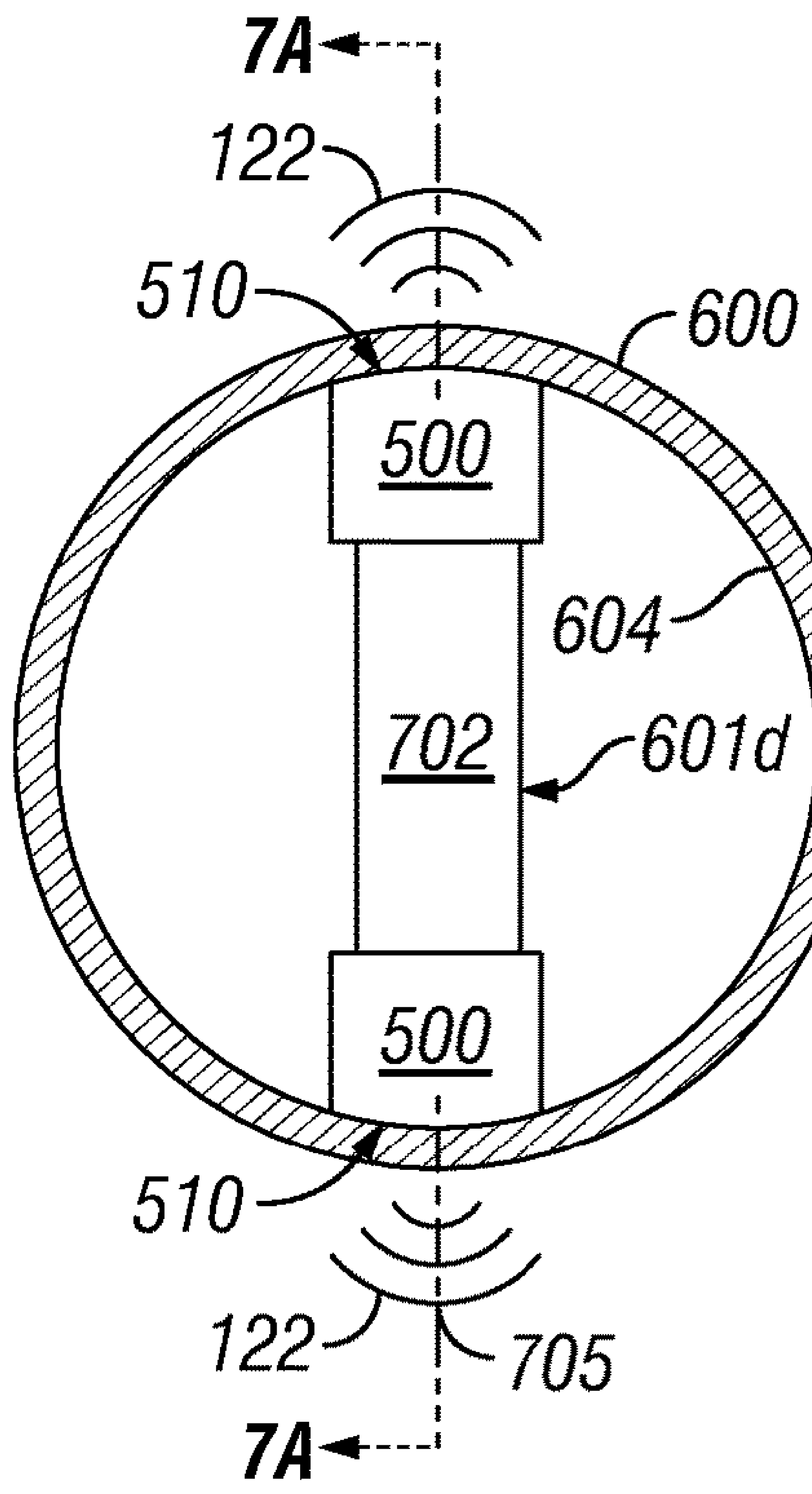

7A
122
510
600
500
604
702
601d
500
510
122
705
7A

FIG. 7B

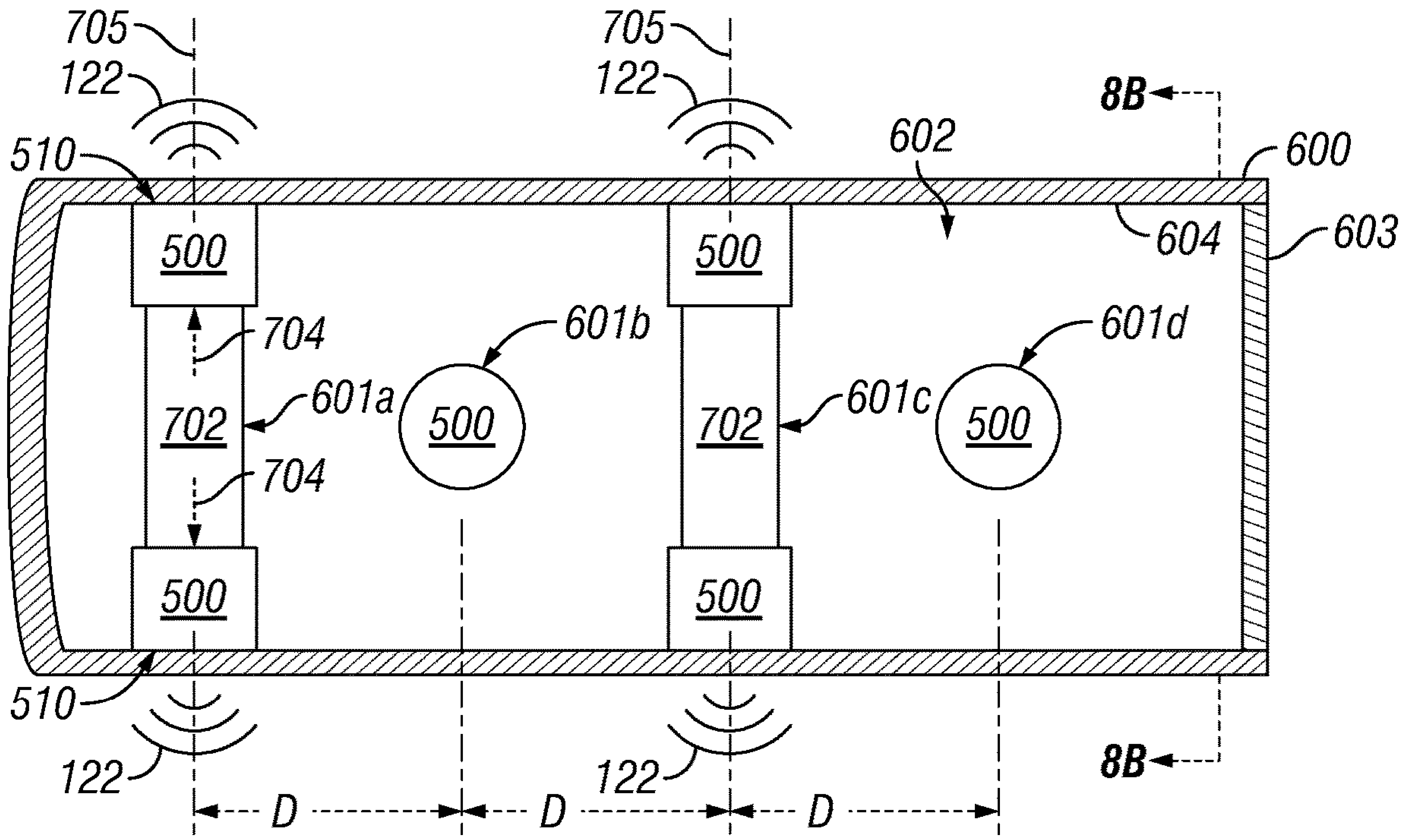

705
705
122
122
8B
510
602
600
500
500
604
603
704
601b
601d
702
601a
500
702
601c
500
704
500
500
510
8B
122
122
D
D
D

FIG. 8A

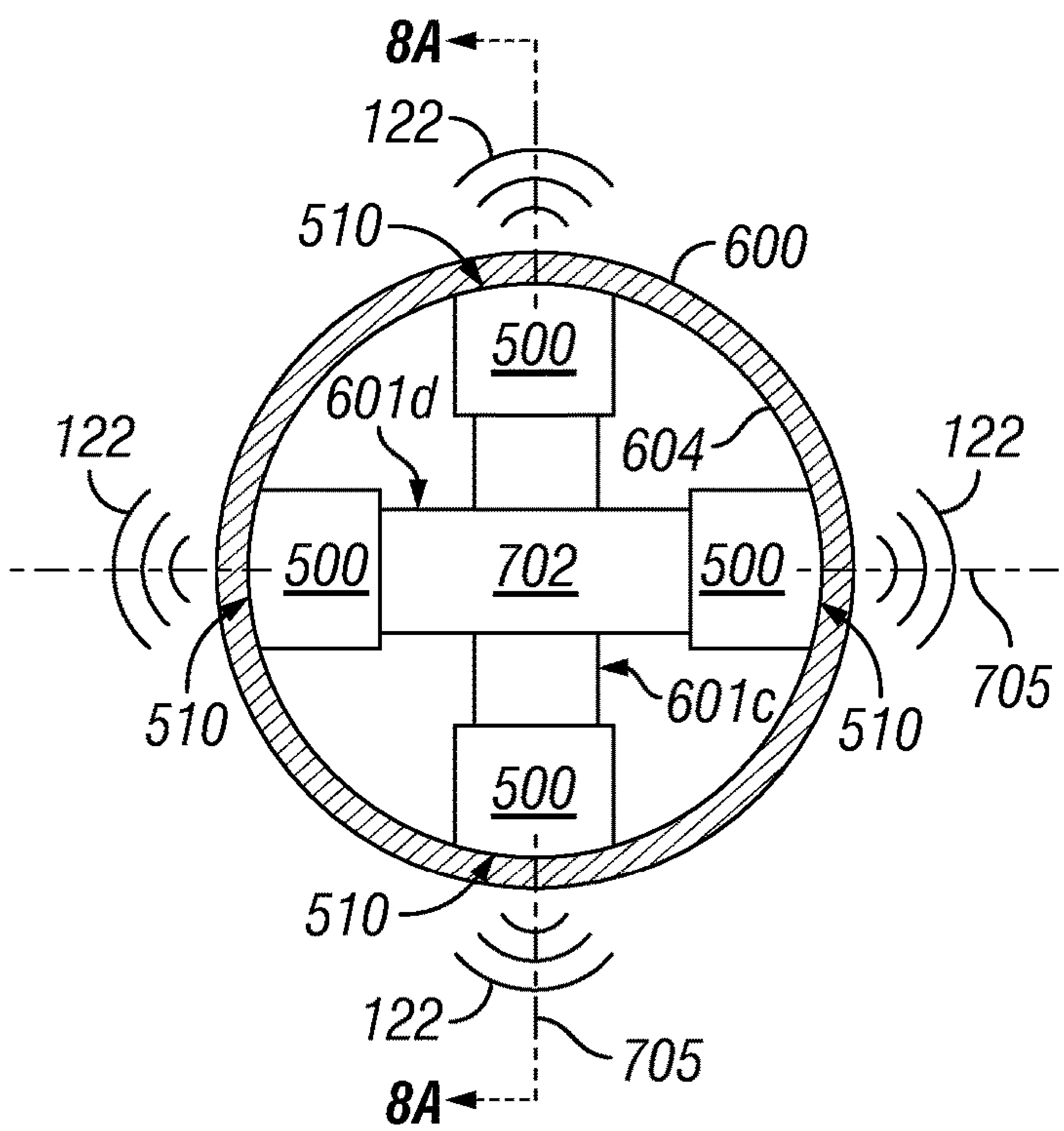

8A
122
510
600
500
601d
604
122
122
500
702
500
705
510
601c
510
500
510
122
705
8A

FIG. 8B

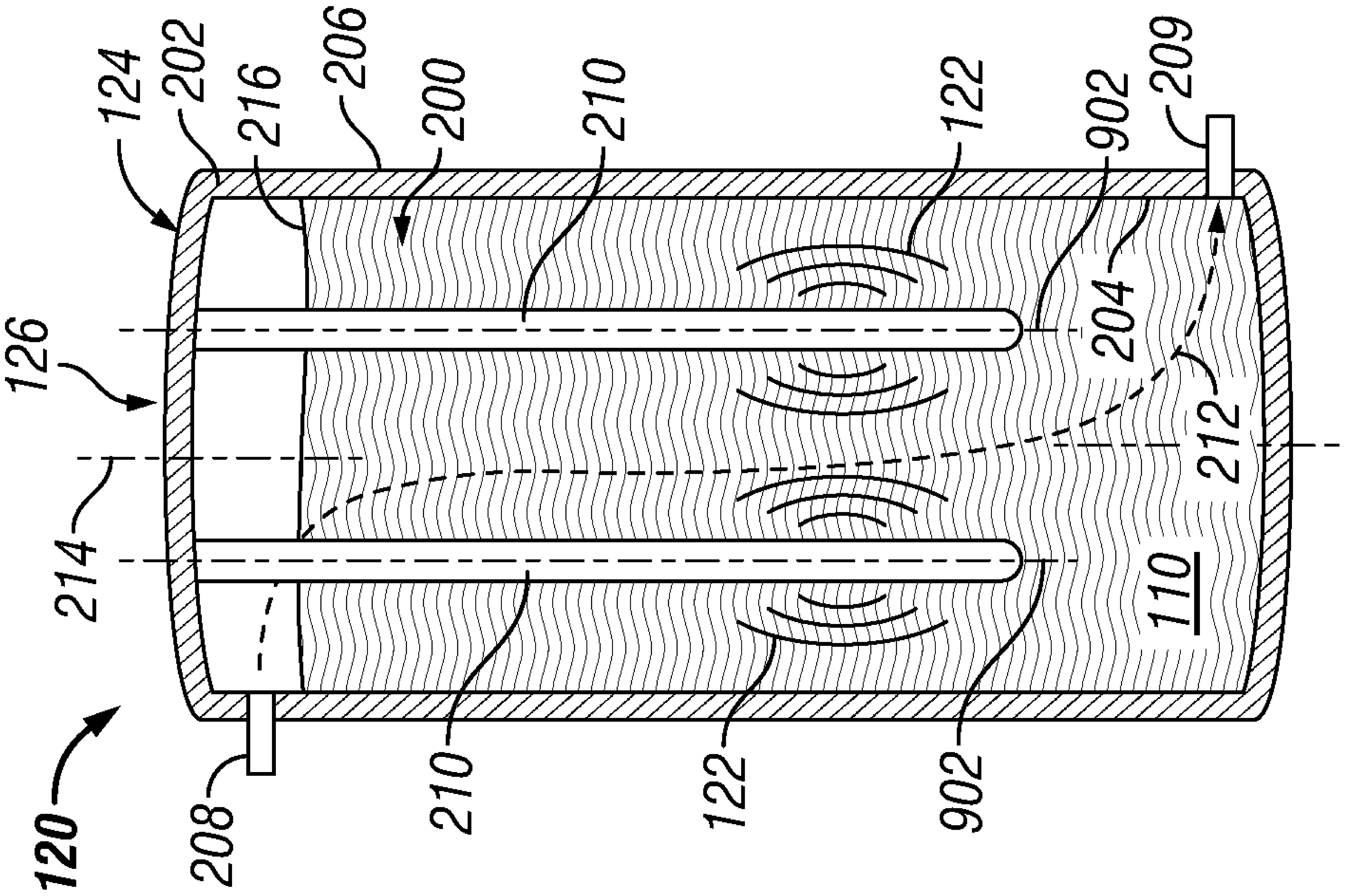

120
124
202
216
206
200
210
122
902
209
126
204
212
214
110
208
210
122
902

FIG. 9B

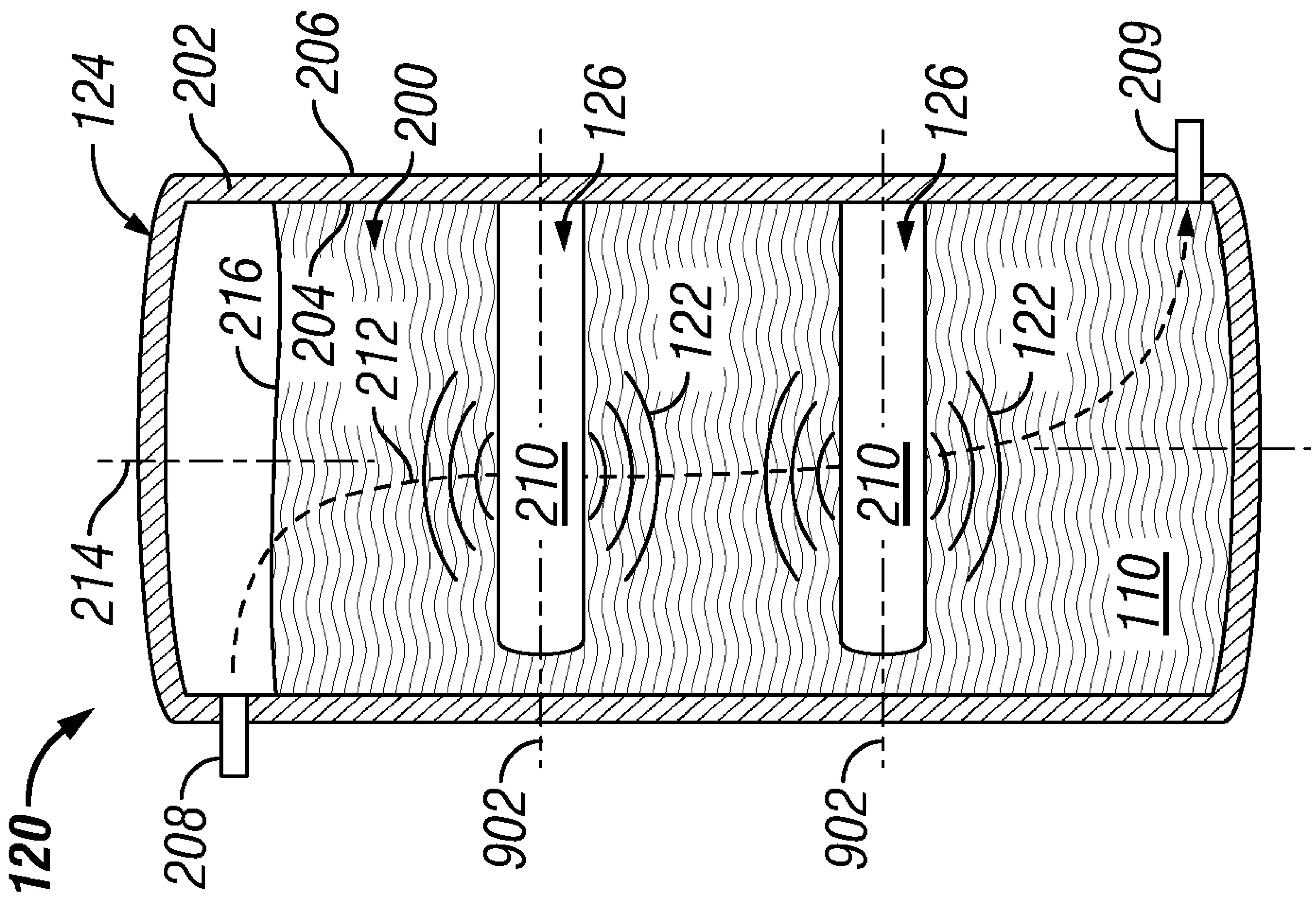

120
124
202
206
200
126
126
209
216
204
212
122
122
214
210
210
110
208
902
902

FIG. 9A

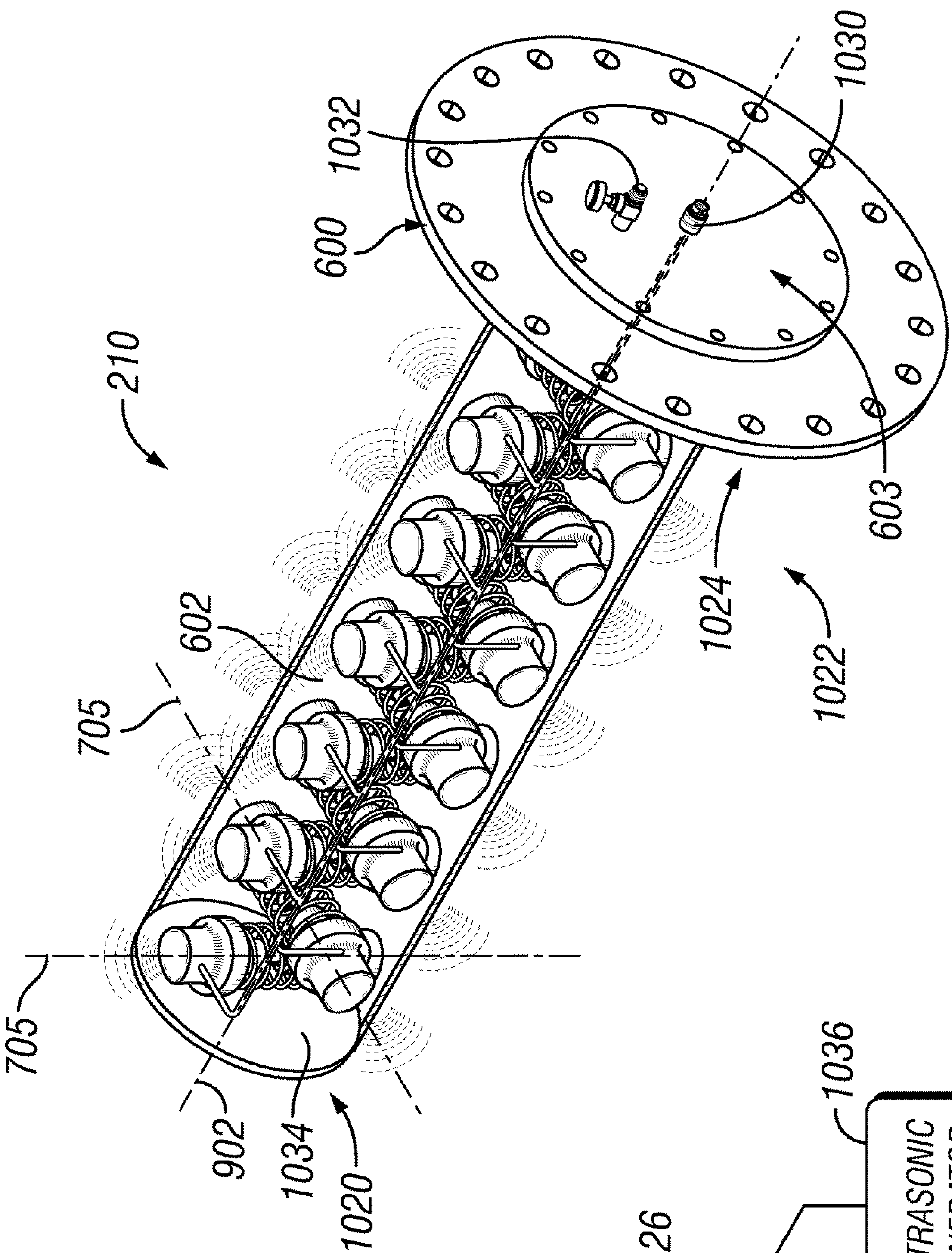


FIG. 10B

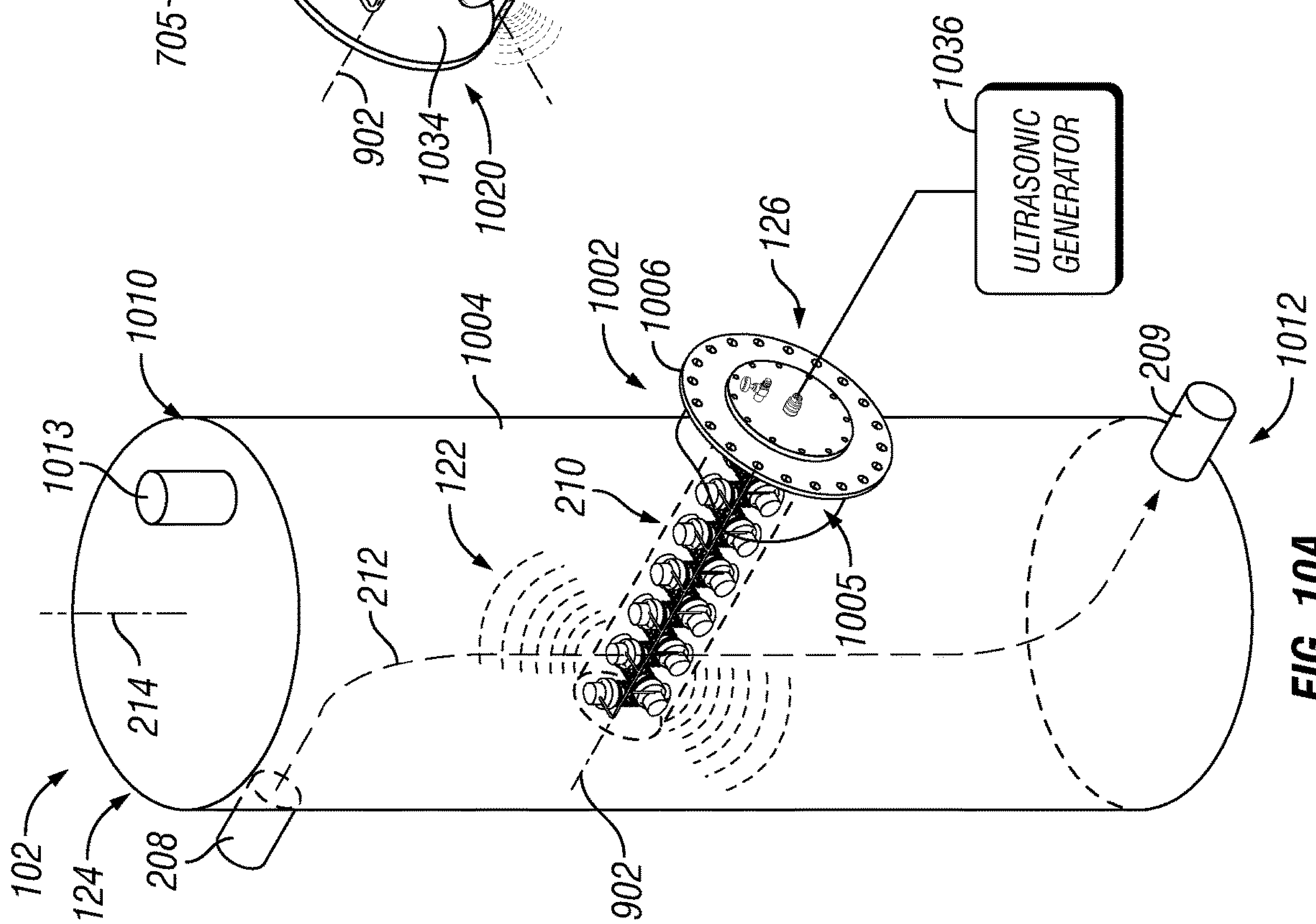


FIG. 10A

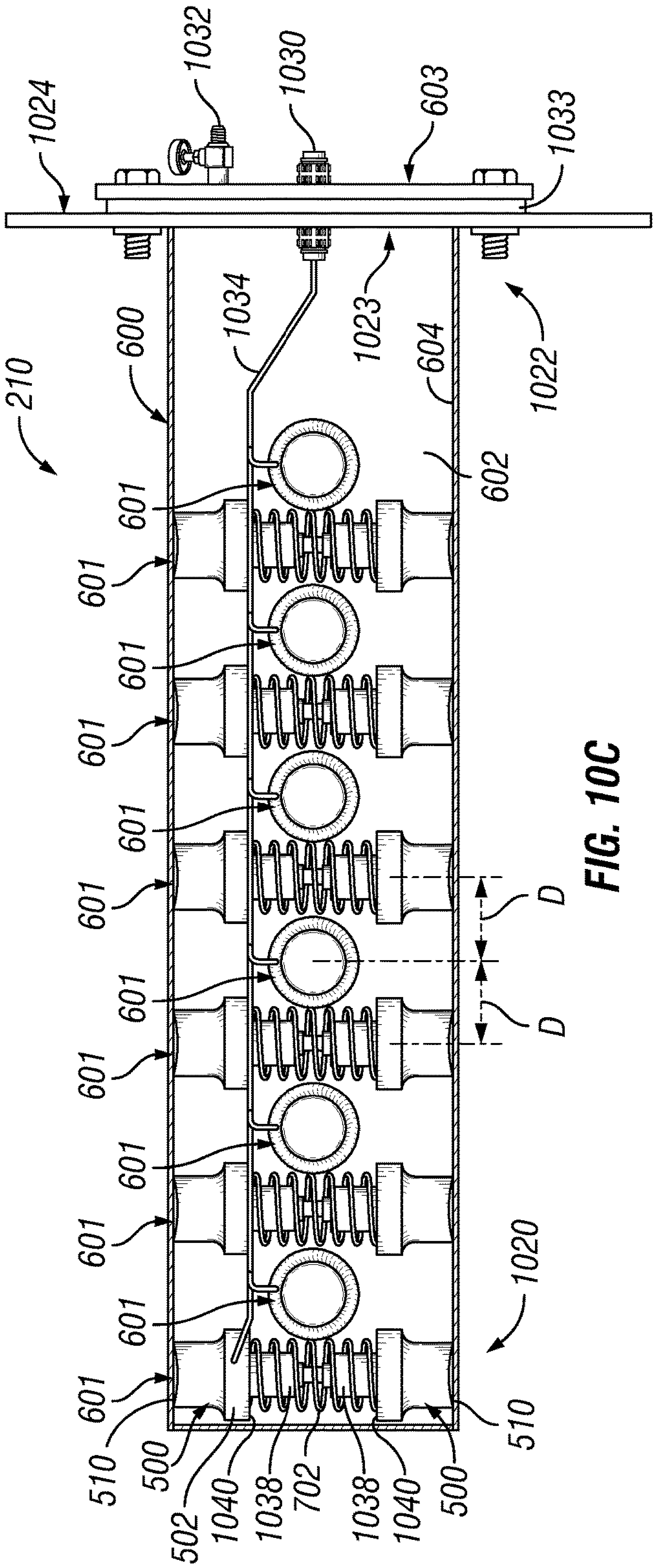


FIG. 10C

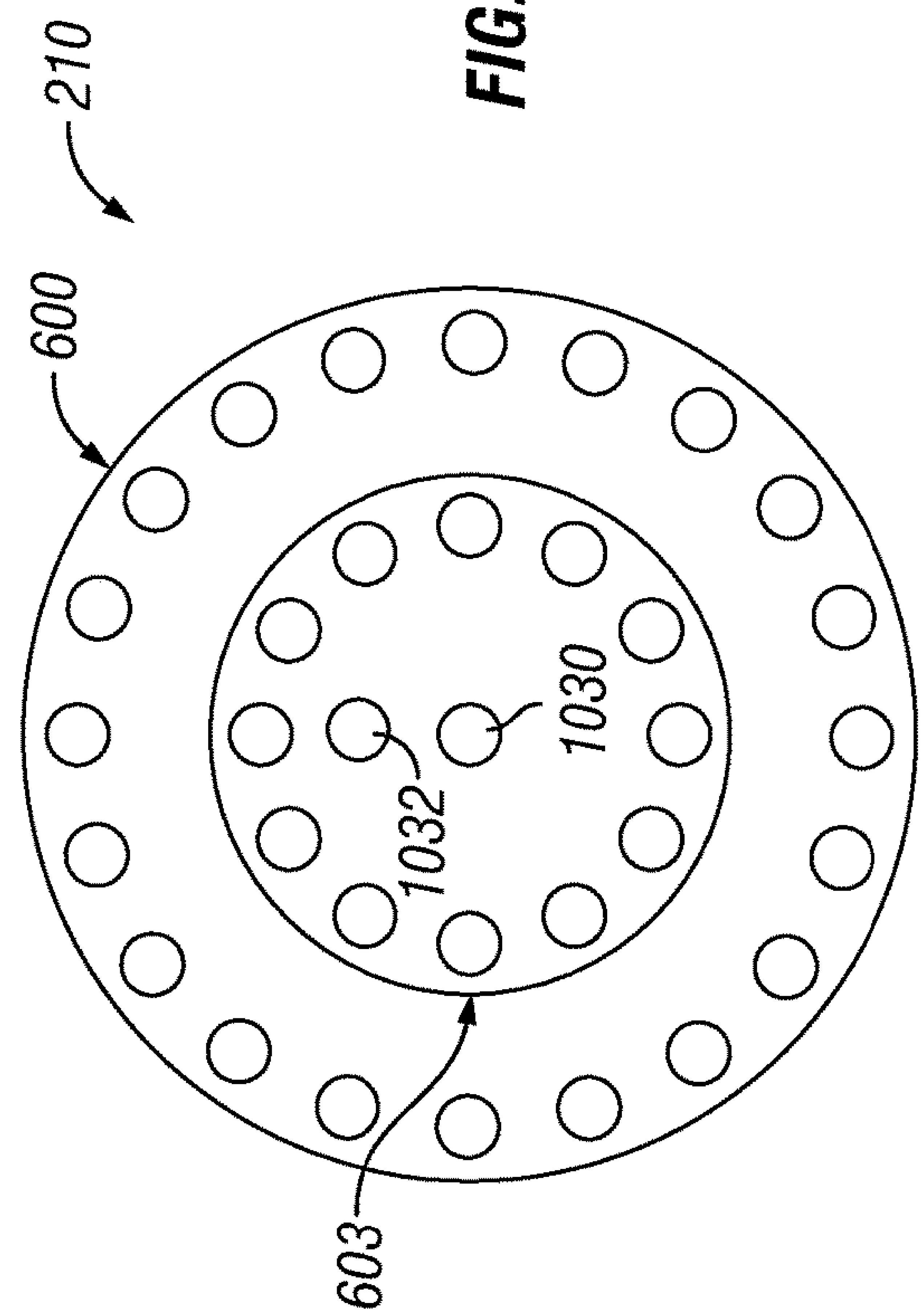


FIG. 10D

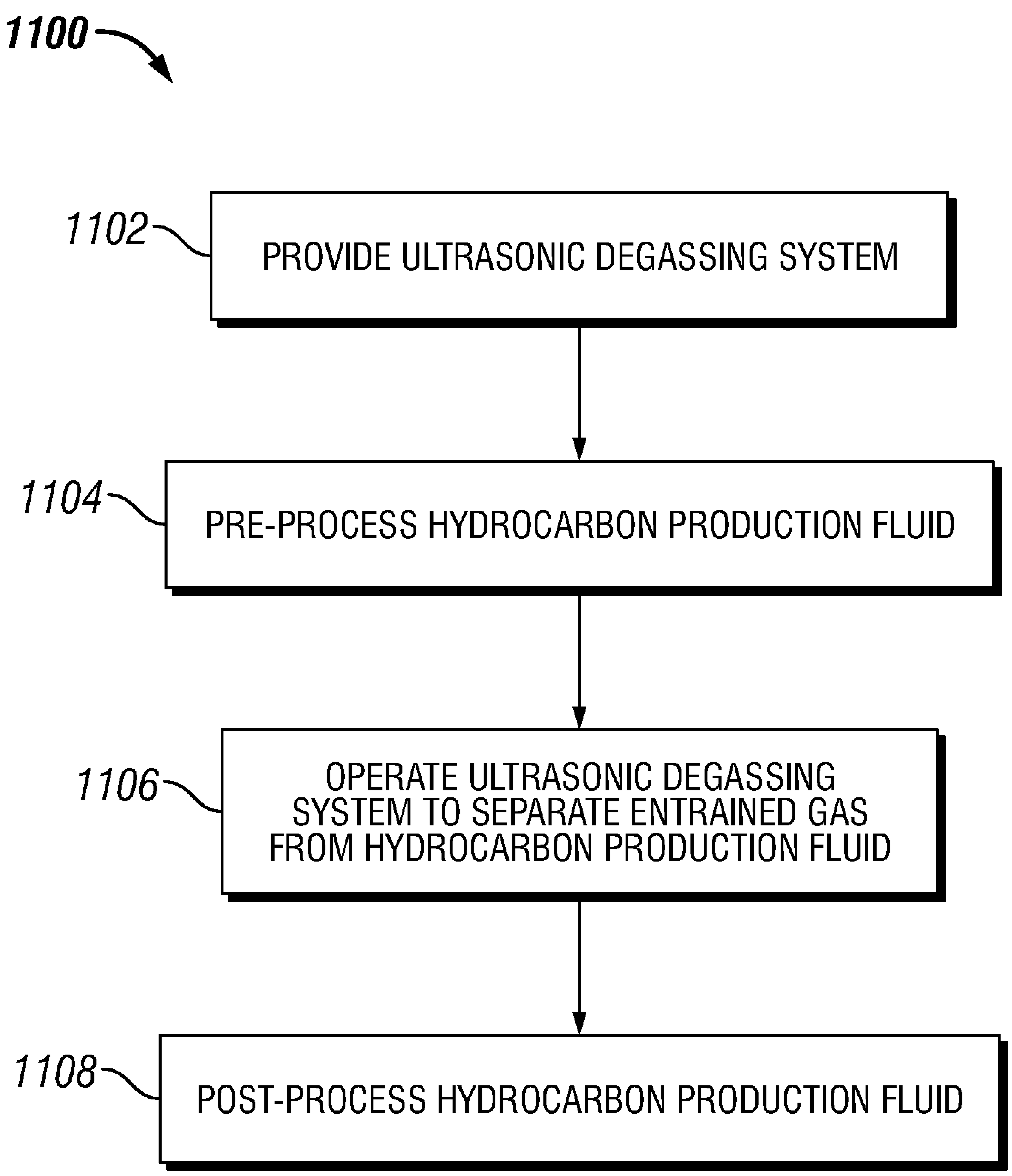

1100
1102
PROVIDE ULTRASONIC DEGASSING SYSTEM
1104
PRE-PROCESS HYDROCARBON PRODUCTION FLUID
1106
OPERATE ULTRASONIC DEGASSING SYSTEM TO SEPARATE ENTRAINED GAS FROM HYDROCARBON PRODUCTION FLUID
1108
POST-PROCESS HYDROCARBON PRODUCTION FLUID

FIG. 11

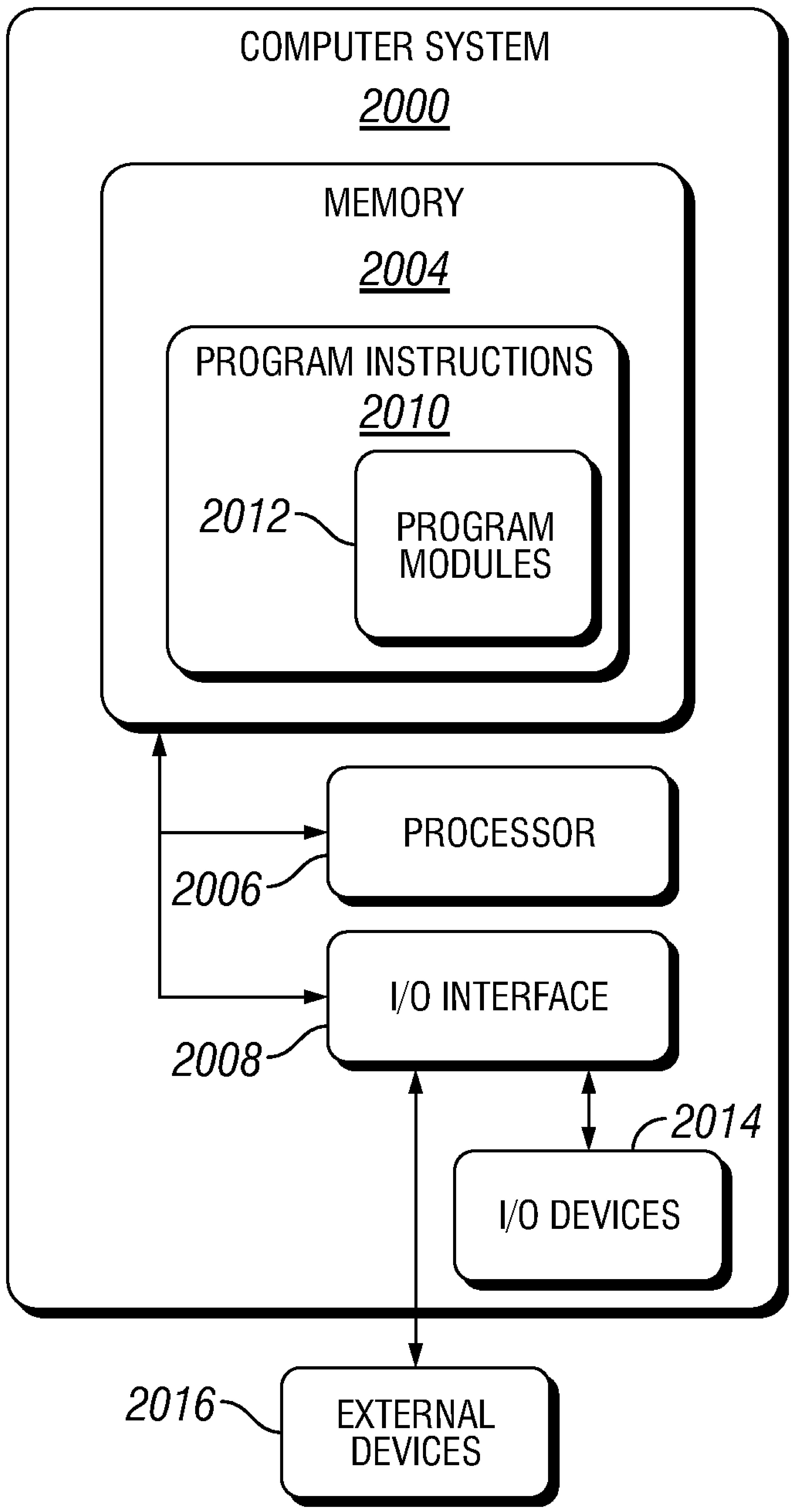

COMPUTER SYSTEM
2000
MEMORY
2004
PROGRAM INSTRUCTIONS
2010
2012
PROGRAM MODULES
PROCESSOR
2006
I/O INTERFACE
2008
2014
I/O DEVICES
2016
EXTERNAL DEVICES

FIG. 12

ULTRASONIC DEGASSING OF HYDROCARBON PRODUCTION FLUID

RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 15/978,477 filed May 14, 2018 and titled "ULTRASONIC DEGASSING OF HYDROCARBON PRODUCTION FLUID", which is hereby incorporated by reference.

FIELD

Embodiments relate generally to processing hydrocarbon production fluid, and more particularly to ultrasonic degassing of hydrocarbon production fluid.

BACKGROUND

Production of hydrocarbons, such as oil and natural gas, typically involves extracting the hydrocarbons trapped in a hydrocarbon reservoir of a subsurface formation. During production operations, production fluid containing hydrocarbons is extracted from the reservoir and directed to the surface by way of a well, often referred to as a "hydrocarbon well" or an "oil well". The production fluid is normally transported to downstream facilities, such as refineries and export terminals, by way of a distribution network of midstream facilities, such as pipelines, tanks and transport vehicles.

In many instances, the production fluid is subjected to various forms of processing to, for example, clean the production fluid of unwanted substances, or otherwise prepare the production fluid for storage, transport and use. For example, raw production fluid flowing from a well may contain a mixture of substances, such as crude oil, natural gas and water, and the raw production fluid may be processed to separate the various substances. This can include separating the water and gas from the production fluid in an effort to obtain production fluid that is predominately oil. The processing is sometimes conducted at the well-site shortly after the production fluid exits the well. For example, the production fluid may be processed at a surface unit located at the well-site to remove water or gas, before the production fluid is introduced into a pipeline, a tank or a transport vehicle of a distribution network.

A point in the distribution where the production fluids move from one entity's ownership or control to another entities ownership or control, is sometimes referred to as a "point of sale" ("POS"). For example, a POS may refer to a point at an outlet valve of a surface unit located at a well-site, where production fluid exits the well-site facilities, and enters a purchaser's pipeline or is loaded into a purchaser's transport vehicle. Often times, production fluids are processed to meet requirements at a POS, or at other points along the distribution network.

SUMMARY

Applicants have recognized that processing hydrocarbon production fluid (referred to here as "production fluid") is an important aspect of hydrocarbon production, distribution and refining, especially in view of the importance that production fluid have a suitable composition, such as a minimal amount of water or entrained gases, to meet requirements for production fluid distribution and use. The importance is ever increasing as requirements for production

fluid composition are becoming more stringent. Applicants have recognized that lowering the gas content of production fluids can reduce the vapor pressure of the production fluid, and that it can be advantageous to significantly reduce the gas content of production fluids given that many purchasers now requiring production fluid to have a relatively low vapor pressure, such as a Reid Vapor Pressure (RVP) below 9. Unfortunately, if production fluid does not meet requirements, the production fluid may be rejected. This can result in direct financial losses due to lost sales of the production fluid, and indirect financial losses associated with further processing of the production fluid to meet requirements, or shut-in of the well from which the production fluid was produced. This can amount to tens-of-thousands of dollars of losses per well, per day.

Applicants have recognized that although some existing production fluid processing techniques are suitable for certain conditions and for certain requirements, existing production fluid processing techniques may not be capable of meeting requirements under certain conditions, especially in the case of heightened requirements. For example, existing techniques for removing entrained gas from production fluid (referred to as "degassing" of the production fluid) involve heating the production fluid to increase the temperature of the production fluid, and rapidly reducing the pressure of the production fluid to cause gas entrained in the production fluid (referred to as "entrained gas") to separate from the production fluid. Although such heating and pressure based techniques can be suitable for certain conditions, they may not be suitable for other conditions. For example, although these techniques can be suitable for use in warm climates, where the required heating is minimal, in cold climates or during relatively cold periods in warm climates, it may not be possible to heat a production fluid to a high enough temperature to facilitate the separation of the entrained gas from the production fluid. This scenario has been observed in cold climates and during relatively cold winters, where significantly increasing the heating of the production fluid is ineffective at causing the entrained gas to separate from the production fluid. As a result, the RVP of the production fluid may not be reduced to an acceptable level to meet purchaser requirements, and the production fluid may be rejected by purchasers. Moreover, even in instances in which it is possible to heat production fluid to a high enough temperature to facilitate the separation of gas from the production fluid, the cost to heat the production fluid can be excessive, and the time required to heat the production fluid can create delays that further increase the costs and complexity of processing the production fluid.

Recognizing these and other shortcomings of existing techniques for degassing production fluid, Applicants have developed novel systems and methods for degassing hydrocarbon production fluid using ultrasonic signals. In some embodiments, an ultrasonic signal is introduced into production fluid including a hydrocarbon fluid mixture of a hydrocarbon liquid and gas entrained in the hydrocarbon liquid (or "entrained gas"), to facilitate the separation and removal of the entrained gas from the hydrocarbon liquid. In some embodiments, an ultrasonic hydrocarbon production fluid degassing system includes a hydrocarbon degassing unit, including a vessel (e.g., a vapor recovery vessel) that directs production fluid along a flowpath, and an ultrasonic transducer system that transmits ultrasonic signals into the production fluid as it travels along the flowpath. The ultrasonic signals cause the entrained gas to separate from the hydrocarbon liquid, and the gas is removed, for example, by way of a vapor recovery system (VRS).

In some embodiments, the ultrasonic signals have a frequency that is effective to cause the entrained gas to separate from the hydrocarbon liquid. For example, the ultrasonic signals may have a frequency in the range of about 20 kilohertz (kHz) to about 40 kHz, such as about 25 kHz. In some embodiments, the ultrasonic transducer system includes one or more ultrasonic transducer heads. For example, the ultrasonic transducer system may include multiple ultrasonic transducer heads that transmit respective subsets of the ultrasonic signals into the production fluid. Such a configuration can increase the exposure of the production fluid to ultrasonic signals, promoting the separation of the entrained gas from the production fluid.

In some embodiments, the ultrasonic transducer system includes one or more ultrasonic transducer units including ultrasonic transducer heads used to generate the ultrasonic signals. For example, the ultrasonic transducer system may include one more ultrasonic transducer units disposed in the flowpath of the production fluid, with each ultrasonic transducer unit including one or more ultrasonic transducer heads that generate the ultrasonic signals that are transmitted into the production fluid. In some embodiments, an ultrasonic transducer unit includes an ultrasonic transducer housing and one or more ultrasonic transducer heads disposed in the housing. For example, an ultrasonic transducer unit may include a cylindrical shaped housing having ultrasonic transducer heads disposed along a length of an interior of housing. The housing may be positioned to intersect the flowpath of the production fluid and, during use, the ultrasonic transducer heads can be activated to transmit ultrasonic signals through the wall of the housing, into the production fluid located around the exterior of the housing. In some embodiments, multiple ultrasonic transducer units are provided in the flowpath of the production fluid. For example, in the case of the vessel being a cylindrical vapor recovery vessel (VRV), such as a vapor recovery tower (VRT) having a flowpath that extends along a length of the interior of vessel, ultrasonic transducer units may be provided along the length of the interior of vessel. Such a configuration of the ultrasonic transducer system may provide for generating ultrasonic signals in a variety of locations, thereby increasing the exposure of the production fluid to ultrasonic signals and further promoting the separation of the entrained gas from the production fluid.

In some embodiments, an ultrasonic transducer unit includes one or more ultrasonic transducer assemblies. An ultrasonic transducer assembly may include one more ultrasonic transducer heads and a transducer biasing member that biases transmission surfaces of the one or more ultrasonic transducer heads into contact with the interior surface of the ultrasonic transducer housing. The resulting contact between the transmission surface of the ultrasonic transducer head and the interior surface of the housing may facilitate the transmission of the ultrasonic signals through the wall of the housing and into the production fluid located around the exterior of the housing.

In some embodiments, an ultrasonic transducer assembly includes two opposite facing ultrasonic transducer heads and a transducer biasing member that biases the transmission surfaces of the multiple ultrasonic transducer heads in opposite directions, into contact with the interior surface of the housing. For example, a transducer biasing member may be disposed between two transducer heads, and provide an outward biasing force to urge the two ultrasonic transducer heads and their respective transmission surfaces outward, in opposite directions from one another, and into contact with opposite portions of the interior surface of the housing. Thus, a single biasing member may operate to position two ultrasonic transducer heads within the housing. Moreover, such a biasing member may facilitate installation, repositioning, or removal of ultrasonic transducer heads. For example, the biasing member of an ultrasonic transducer assembly may be compressed to retract the ultrasonic transducer heads, enabling the ultrasonic transducer assembly (including the pair of ultrasonic transducer heads and the biasing member) to be installed into, repositioned within, or removed from the interior of the housing. The biasing member may be decompressed (or expanded) to bias the transmission surfaces of ultrasonic transducer heads into contact with the interior surface of the housing, securing the ultrasonic transducer assembly in place within the housing.

In some embodiments, multiple ultrasonic transducer assemblies are disposed inside the ultrasonic transducer housing. For example, multiple ultrasonic transducer assemblies may be disposed along a length of the interior of the housing, in series and linearly offset from one another. In some embodiments, the orientations of the ultrasonic transducer assemblies is varied. For example, adjacent ultrasonic transducer assemblies may be angularly offset from one another. In some instances, each of the transducer assemblies may be offset from adjacent transducer assemblies by an offset angle of 90°, such that a first ultrasonic transducer assembly is oriented an angle of 0°, a second ultrasonic transducer assembly (adjacent the first ultrasonic transducer assembly) is oriented an angle of 90°, a third ultrasonic transducer assembly (adjacent the second ultrasonic transducer assembly) is oriented an angle of 0°, and so forth. Such a configuration of the ultrasonic transducer unit may provide for generating the ultrasonic signals in a variety of locations and orientations, thereby increasing the exposure of the production fluid to ultrasonic signals to promote the separation of the entrained gas from the production fluid.

In some embodiments, a production fluid ultrasonic degassing system is employed in combination with other processing systems to further increase the effectiveness of the degassing and processing of the production fluid. For example, a production fluid processing system may include an ultrasonic degassing unit, a water separation system and a heater treater system. The water separation system may separate and remove water from the production fluid, and the ultrasonic production fluid degassing system and the heater treater system may work to separate and remove entrained gas from the production fluid. The ultrasonic production fluid degassing system may be employed at various locations and stages in the production fluid processing system. For example, the ultrasonic degassing unit may be a component of a well-site surface facility, that provides for separating and removing entrained gas from production fluid, upstream of a point of sale (POS) from a producer (e.g., a well operator) to a midstream entity (e.g., an oil and gas purchaser). The well-site surface facility may include, for example, a production fluid processing system including the ultrasonic production fluid degassing system, and a water separation system and a heater treater system located upstream of the ultrasonic degassing unit.

Provided in some embodiments is a hydrocarbon fluid processing system including an ultrasonic hydrocarbon degassing unit including: a vertically oriented vapor recovery vessel adapted to direct flow of a hydrocarbon fluid mixture along a flowpath, from an upper end of the vertically oriented vapor recovery vessel to a lower end of the vertically oriented vapor recovery vessel (the hydrocarbon fluid mixture including a hydrocarbon liquid and a gas entrained in the hydrocarbon liquid); and an ultrasonic transducer system disposed in an interior of the vertically oriented vapor recovery vessel and in the flowpath. The ultrasonic transducer system adapted to transmit ultrasonic signals into the hydrocarbon fluid mixture as the hydrocarbon fluid mixture flows along the flowpath, and the ultrasonic signals adapted to separate the gas from the hydrocarbon liquid.

In certain embodiments, the ultrasonic signals include acoustic signals having a frequency in the range of 23 kHz to 27 kHz. In some embodiments, the ultrasonic signals include acoustic signals having a frequency of 25 kHz. In certain embodiments, the hydrocarbon fluid mixture includes water, the hydrocarbon fluid processing system further includes a water separating system adapted to remove the water from the hydrocarbon fluid mixture, and the ultrasonic hydrocarbon degassing unit is located downstream of the water separating system such that the ultrasonic signals are transmitted into the hydrocarbon fluid mixture by the ultrasonic hydrocarbon degassing unit after the water is removed from the hydrocarbon fluid mixture by the water separating system. In some embodiments, the vertically oriented vapor recovery vessel includes a vapor recover tower. In certain embodiments, the hydrocarbon fluid processing system further includes a vapor recovery system coupled to the vertically oriented vapor recovery vessel, and the vapor recovery system is adapted to remove the gas separated from the hydrocarbon liquid. In some embodiments, the vertically oriented vapor recovery vessel includes a low pressure chamber adapted to collect the gas separated from the hydrocarbon liquid at the upper end of the vertically oriented vapor recovery vessel, and the vapor recovery system is adapted to remove the gas separated from the hydrocarbon liquid from the upper end of the vertically oriented vapor recovery vessel. In certain embodiments, the ultrasonic transducer system includes an ultrasonic transducer unit including a plurality of ultrasonic transducer heads. In some embodiments, the ultrasonic transducer system includes an ultrasonic transducer unit suspended within the interior of the vertically oriented vapor recovery vessel. In certain embodiments, the ultrasonic transducer system includes an ultrasonic transducer unit coupled to a wall of the vertically oriented vapor recovery vessel. In some embodiments, the ultrasonic transducer unit extends laterally in the interior of the vertically oriented vapor recovery vessel, in an orientation perpendicular to a longitudinal axis of the vertically oriented vapor recovery vessel. In certain embodiments, the ultrasonic transducer system includes an ultrasonic transducer unit coupled to an end cap of the vertically oriented vapor recovery vessel. In some embodiments, the ultrasonic transducer unit extends longitudinally into an interior of the vertically oriented vapor recovery vessel, in an orientation parallel to a longitudinal axis of the vertically oriented vapor recovery vessel. In certain embodiments, the ultrasonic transducer system includes a plurality of ultrasonic transducer units disposed along a length of the vertically oriented vapor recovery vessel. In some embodiments, the ultrasonic transducer system includes: a first ultrasonic transducer unit including a first plurality of ultrasonic transducer heads disposed in series along a first axis perpendicular to the flowpath, and adapted to transmit a first subset of the ultrasonic signals into the hydrocarbon fluid mixture as the hydrocarbon fluid flows along the flowpath; and a second ultrasonic transducer unit including a second plurality of ultrasonic transducer heads disposed in series along a second axis perpendicular to the flowpath, and adapted to transmit a second subset of the ultrasonic signals into the hydrocarbon fluid mixture as the hydrocarbon fluid mixture flows along the flowpath. The first axis is located above the second axis such that the first subset of the ultrasonic signals is transmitted into the hydrocarbon fluid mixture upstream of the second subset of the ultrasonic signals being transmitted into the hydrocarbon fluid.

Provided in some embodiments is a hydrocarbon fluid processing system including an ultrasonic hydrocarbon degassing unit including: a vapor recovery vessel adapted to direct flow of a hydrocarbon fluid mixture along a flowpath extending through an interior of the vapor recovery vessel (the hydrocarbon fluid mixture including a hydrocarbon liquid and a gas entrained in the hydrocarbon liquid); and an ultrasonic transducer system disposed inside the vapor recovery vessel and in the flowpath of the hydrocarbon fluid mixture. The ultrasonic transducer system adapted to transmit ultrasonic signals into the hydrocarbon fluid mixture along the flowpath, and the ultrasonic signals adapted to separate the gas from the hydrocarbon liquid.

In some embodiments, the ultrasonic signals include acoustic signals having a frequency in the range of 23 kHz to 27 kHz. In certain embodiments, the hydrocarbon fluid mixture includes water, the hydrocarbon fluid processing system further includes a water separating system adapted to remove the water from the hydrocarbon fluid mixture, and the ultrasonic hydrocarbon degassing unit is located downstream of the water separating system such that the ultrasonic signals are transmitted into the hydrocarbon fluid mixture by the ultrasonic hydrocarbon degassing unit after the water is removed from the hydrocarbon fluid mixture by the water separating system. In some embodiments, the hydrocarbon fluid processing system further includes a vapor recovery system coupled to the vapor recovery vessel. The vapor recovery system adapted to remove the gas separated from the hydrocarbon liquid. In certain embodiments, the vapor recovery vessel includes a vapor recover tower.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram that illustrates a hydrocarbon production fluid processing environment in accordance with one or more embodiments.

FIG. **2** is a diagram that illustrates a cross-sectioned side view of an ultrasonic degassing unit in accordance with one or more embodiments.

FIG. **3** is a diagram that illustrates a cross-sectioned side view of an ultrasonic degassing unit including ultrasonic transducer units positioned in various locations accordance with one or more embodiments.

FIG. **4** is a diagram that illustrates a set of ultrasonic transducer units positioned in a helical pattern in accordance with one or more embodiments.

FIG. **5** is a diagram that illustrates a cross-sectioned side view of an example ultrasonic transducer head in accordance with one or more embodiments.

FIG. **6** is a diagram that illustrates a cross-sectioned side view of an ultrasonic transducer unit in accordance with one or more embodiments.

FIGS. **7**A, **7**B, **8**A and **8**B are diagrams that illustrate ultrasonic transducer units including ultrasonic transducer assemblies that each include a plurality of ultrasonic transducer heads in accordance with one or more embodiments.

FIG. **9**A is a diagram that illustrates an ultrasonic hydrocarbon degassing system including an ultrasonic transducer system having laterally oriented elongated ultrasonic transducer units in accordance with one or more embodiments.

FIG. **9**B is a diagram that illustrates an ultrasonic hydrocarbon degassing system including an ultrasonic transducer system having longitudinally oriented elongated ultrasonic transducer units in accordance with one or more embodiments.

FIGS. **10**A-**10**D are diagrams that illustrate an ultrasonic degassing unit in accordance with one or more embodiments.

FIG. **11** is a flowchart that illustrates a method of degassing hydrocarbon production fluid in accordance with one or more embodiments.

FIG. **12** is a diagram that illustrates an example computer system in accordance with one or more embodiments.

While this disclosure is susceptible to various modifications and alternative forms, specific embodiments are shown by way of example in the drawings and will be described in detail. The drawings may not be to scale. It should be understood that the drawings and the detailed descriptions are not intended to limit the disclosure to the particular form disclosed, but are intended to disclose modifications, equivalents, and alternatives falling within the spirit and scope of the present disclosure as defined by the claims.

DETAILED DESCRIPTION

Described are embodiments of novel systems and methods for degassing hydrocarbon production fluid using ultrasonic signals. In some embodiments, an ultrasonic signal is introduced into production fluid including a hydrocarbon fluid mixture of a hydrocarbon liquid and gas entrained in the hydrocarbon liquid (or "entrained gas"), to facilitate the separation and removal of the entrained gas from the hydrocarbon liquid. In some embodiments, an ultrasonic hydrocarbon production fluid degassing system includes a hydrocarbon degassing unit, including a vessel (e.g., a vapor recovery vessel) that directs production fluid along a flowpath, and an ultrasonic transducer system that transmits ultrasonic signals into the production fluid as it travels along the flowpath. The ultrasonic signals cause the entrained gas to separate from the hydrocarbon liquid, and the gas is removed, for example, by way of a vapor recovery system (VRS).

In some embodiments, the ultrasonic signals have a frequency that is effective to cause the entrained gas to separate from the hydrocarbon liquid. For example, the ultrasonic signals may have a frequency in the range of about 20 kilohertz (kHz) to about 40 kHz, such as about 25 kHz. In some embodiments, the ultrasonic transducer system includes one or more ultrasonic transducer heads. For example, the ultrasonic transducer system may include multiple ultrasonic transducer heads that transmit respective subsets of the ultrasonic signals into the production fluid. Such a configuration can increase the exposure of the production fluid to ultrasonic signals, promoting the separation of the entrained gas from the production fluid.

In some embodiments, the ultrasonic transducer system includes one or more ultrasonic transducer units including ultrasonic transducer heads used to generate the ultrasonic signals. For example, the ultrasonic transducer system may include one more ultrasonic transducer units disposed in the flowpath of the production fluid, with each ultrasonic transducer unit including one or more ultrasonic transducer heads that generate the ultrasonic signals that are transmitted into the production fluid. In some embodiments, an ultrasonic transducer unit includes an ultrasonic transducer housing and one or more ultrasonic transducer heads disposed in the housing. For example, an ultrasonic transducer unit may include a cylindrical shaped housing having ultrasonic transducer heads disposed along a length of an interior of housing. The housing may be positioned to intersect the flowpath of the production fluid and, during use, the ultrasonic transducer heads can be activated to transmit ultrasonic signals through the wall of the housing, into the production fluid located around the exterior of the housing. In some embodiments, multiple ultrasonic transducer units are provided in the flowpath of the production fluid. For example, in the case of the vessel being a cylindrical vapor recovery vessel (VRV), such as a vapor recovery tower (VRT) having a flowpath that extends along a length of the interior of vessel, ultrasonic transducer units may be provided along the length of the interior of vessel. Such a configuration of the ultrasonic transducer system may provide for generating ultrasonic signals in a variety of locations, thereby increasing the exposure of the production fluid to ultrasonic signals and further promoting the separation of the entrained gas from the production fluid.

In some embodiments, an ultrasonic transducer unit includes one or more ultrasonic transducer assemblies. An ultrasonic transducer assembly may include one more ultrasonic transducer heads and a transducer biasing member that biases transmission surfaces of the one or more ultrasonic transducer heads into contact with the interior surface of the ultrasonic transducer housing. The resulting contact between the transmission surface of the ultrasonic transducer head and the interior surface of the housing may facilitate the transmission of the ultrasonic signals through the wall of the housing and into the production fluid located around the exterior of the housing.

In some embodiments, an ultrasonic transducer assembly includes two opposite facing ultrasonic transducer heads and a transducer biasing member that biases the transmission surfaces of the multiple ultrasonic transducer heads in opposite directions, into contact with the interior surface of the housing. For example, a transducer biasing member may be disposed between two transducer heads, and provide an outward biasing force to urge the two ultrasonic transducer heads and their respective transmission surfaces outward, in opposite directions from one another, and into contact with opposite portions of the interior surface of the housing. Thus, a single biasing member may operate to position two ultrasonic transducer heads within the housing. Moreover, such a biasing member may facilitate installation, repositioning, or removal of ultrasonic transducer heads. For example, the biasing member of an ultrasonic transducer assembly may be compressed to retract the ultrasonic transducer heads, enabling the ultrasonic transducer assembly (including the pair of ultrasonic transducer heads and the biasing member) to be installed into, repositioned within, or removed from the interior of the housing. The biasing member may be decompressed (or expanded) to bias the transmission surfaces of ultrasonic transducer heads into contact with the interior surface of the housing, securing the ultrasonic transducer assembly in place within the housing.

In some embodiments, multiple ultrasonic transducer assemblies are disposed inside the ultrasonic transducer housing. For example, multiple ultrasonic transducer assemblies may be disposed along a length of the interior of the housing, in series and linearly offset from one another. In some embodiments, the orientations of the ultrasonic transducer assemblies is varied. For example, adjacent ultrasonic transducer assemblies may be angularly offset from one another. In some instances, each of the transducer assemblies may be offset from adjacent transducer assemblies by an offset angle of 90°, such that a first ultrasonic transducer assembly is oriented an angle of 0°, a second ultrasonic transducer assembly (adjacent the first ultrasonic transducer assembly) is oriented an angle of 90°, a third ultrasonic transducer assembly (adjacent the second ultrasonic transducer assembly) is oriented an angle of 0°, and so forth. Such a configuration of the ultrasonic transducer unit may provide for generating the ultrasonic signals in a variety of locations and orientations, thereby increasing the exposure of the production fluid to ultrasonic signals to promote the separation of the entrained gas from the production fluid.

In some embodiments, a production fluid ultrasonic degassing system is employed in combination with other processing systems to further increase the effectiveness of the degassing and processing of the production fluid. For example, a production fluid processing system may include an ultrasonic degassing unit, a water separation system and a heater treater system. The water separation system may separate and remove water from the production fluid, and the ultrasonic production fluid degassing system and the heater treater system may work to separate and remove entrained gas from the production fluid. The ultrasonic production fluid degassing system may be employed at various locations and stages in the production fluid processing system. For example, the ultrasonic degassing unit may be a component of a well-site surface facility, that provides for separating and removing entrained gas from production fluid, upstream of a point of sale (POS) from a producer (e.g., a well operator) to a midstream entity (e.g., an oil and gas purchaser). The well-site surface facility may include, for example, a production fluid processing system including the ultrasonic production fluid degassing system, and a water separation system and a heater treater system located upstream of the ultrasonic degassing unit.

Although certain embodiments are described with regard to removing entrained gas from a hydrocarbon production fluid, embodiments can be applied in various context. For example, embodiments of the ultrasonic degassing system can be employed for separating gas from other fluids, such as separating entrained gas from refined fuels, detergents, or other liquids which are susceptible to or containing entrained gas.

FIG. **1** is a diagram that illustrates a hydrocarbon production fluid processing environment, including a hydrocarbon production fluid processing system ("hydrocarbon processing system") **100**, in accordance with one or more embodiments. In the illustrated embodiment, the hydrocarbon processing system **100** includes an ultrasonic hydrocarbon production fluid degassing system ("ultrasonic degassing system") **102**, an upstream hydrocarbon production fluid processing system ("upstream processing system") **104**, a downstream hydrocarbon production fluid processing system ("downstream processing system") **106**, and a process controller **108**. As described, in some embodiments, the hydrocarbon processing system **100** is employed to process a hydrocarbon production fluid ("production fluid") **110**.

In some embodiments, the production fluid **110** includes a hydrocarbon fluid mixture, including a hydrocarbon liquid and gas entrained in the hydrocarbon liquid. The hydrocarbon liquid may include, for example, crude oil and the gas may include, for example, natural gas. The production fluid **110** may include production fluid, such as mixture of produced oil, gas and water, provided from an outlet valve of a hydrocarbon well. In such an embodiment, the hydrocarbon processing system **100** may be a component of a well-site surface facilities, that provides for separating and removing entrained gas from the production fluid **110**, upstream of a point of sale (POS) from a producer (e.g., a well operator) to a midstream entity (e.g., an oil and gas purchaser). In some embodiments, the hydrocarbon processing system **100** is a component of midstream or downstream facilities, for processing the production fluid **110** at various stages of distribution or use.

In some embodiments, the ultrasonic degassing system **102** employs ultrasonic signals to separate entrained gas from the production fluid **110**. For example, if the production fluid **110** includes crude oil and natural gas entrained in the crude oil, the ultrasonic degassing system **102** may employ ultrasonic signals to separate the entrained natural gas from the crude oil. In some embodiments, the ultrasonic degassing system **102** includes one or more ultrasonic hydrocarbon degassing units ("ultrasonic degassing units") **120**. An ultrasonic degassing unit **120** may operate to introduce ultrasonic signals **122** into the production fluid **110**, to facilitate the separation of entrained gas from the production fluid **110**. Continuing with the above example, an ultrasonic degassing unit **120** may introduce ultrasonic signals **122** into the production fluid **110**, to cause the entrained natural gas to separate from the crude oil.

In some embodiments, an ultrasonic degassing unit **120** includes a vessel **124** and an ultrasonic transducer system **126**. In some embodiments, the vessel **124** defines a flowpath of the production fluid **110**, and the ultrasonic transducer system **126** operates to generate ultrasonic signals **122** that are transmitted into the production fluid **110** as it travels along the flowpath defined by the vessel **124**. In some embodiments, the vessel **124** is a conduit, such as a pipe, tank, or a vapor recovery vessel (VRV), such as a vertically oriented vapor recover tower (VRT) of a vapor recovery system that directs the flow of the production fluid **110**. For example, the vessel **124** may be VRT having an interior that defines a vertical flowpath of the production fluid **110**, extending from an upper end of the VRT to a lower end of the VRT, and the ultrasonic transducer system **126** may generate ultrasonic signals **122** that are transmitted into the production fluid **110** located inside the VRT as it travels along the flowpath defined by the vessel **124**.

The ultrasonic signals **122** may be generated with a sufficient frequency to cause entrained gas to separate from fluid of the production fluid **110**. For example, the ultrasonic signals **122** may be of a sufficient frequency to cause entrained natural gas to separate from the crude oil of the production fluid **110**. In some embodiments, the ultrasonic signals **122** have a frequency in the range of about 20 kilohertz (kHz) to about 40 kHz. In some embodiment, the ultrasonic signals **122** have a frequency in the range of about 23 kilohertz (kHz) to about 27 kHz. For example, the ultrasonic signals **122** may have a frequency of about 25 kHz. The radiating of the ultrasonic signals **122** into the production fluid **110** may create alternating high-pressure and low-pressure cycles at a rate corresponding to the frequency of the ultrasonic signals **122**. The low-pressure cycle may create a vacuum that generates bubbles, which are filled with the entrained gas of the production fluid **110**. These bubbles may rise to the surface of the production fluid **110**, where they can be separated from the production fluid **110**. In some embodiments, the ultrasonic degassing system **102** includes a vapor recovery system **128**, and the separated gas is captured and removed by the vapor recovery system **128**. The recovered gas may, for example, be sold, flared-off, or otherwise disposed of in a responsible and environmentally safe manner.

In some embodiments, the upstream processing system **104** operates to conduct pre-processing of the production fluid **110**, upstream of the ultrasonic degassing system **102**.

Pre-processing of the production fluid **110** may refer to processing of the production fluid **110** that occurs prior to the production fluid **110** being subjected to the ultrasonic signals **122** of the ultrasonic degassing system **102**. The upstream processing system **104** may include, for example, a water separator system, a heater treater system or a pressure reduction system. A water separator system may operate to separate and remove some or all of water contained in the production fluid **110**, from the production fluid **110**. A heater treater system may operate to heat the production fluid **110** to, for example, promote the separation of entrained gas from the production fluid **110**. A pressure reduction system may operate to reduce the pressure of the production fluid **110** to, for example, promote the separation of entrained gas from the production fluid **110**. In some embodiments, the upstream processing system **104** is a component of a well-site surface facility. For example, an inlet of the upstream processing system **104** may be coupled to an outlet of a production tree of a hydrocarbon well, and receive "raw" or "unprocessed" production fluid **110** (e.g., including a hydrocarbon fluid mixture of crude oil, water and natural gas) from the hydrocarbon well. Although the illustrated embodiment includes an upstream processing system **104**, in some embodiments, the hydrocarbon processing system **100** does not include an upstream processing system. For example, the ultrasonic degassing system **102** may be coupled to an outlet of a production tree of a hydrocarbon well, and receive raw production fluid **110** from the hydrocarbon well without pre-processing.

In some embodiments, the downstream processing system **106** operates to conduct post-processing of the production fluid **110**, downstream of the ultrasonic degassing system **102**. Post-processing may refer to processing of the production fluid **110** subsequent to the production fluid **110** being subjected to the ultrasonic signals **122** of the ultrasonic degassing system **102**. For example, post-processing may include processing of the "degassed" production fluid **110** exiting the ultrasonic degassing system **102**. The downstream processing system **106** may include, for example, a water separator system, a heater treater system or a pressure reduction system. In some embodiments, the downstream processing system **106** is a component of a well-site surface facility. For example, an outlet of the downstream processing system **106** may be coupled to an outlet of well-site surface facilities that is coupled to a midstream facility, such as a storage facility (e.g., a storage tank), a valve for loading the production fluid onto a transport vehicle or a pipeline. Although the illustrated embodiment includes a downstream processing system **106**, in some embodiments, the hydrocarbon processing system **100** does not include a downstream processing system. For example, an outlet of the ultrasonic degassing system **102** may be coupled to a midstream facility, such as a storage tank, a valve for loading the production fluid onto a transport vehicle, or a pipeline, and the degassed production fluid **110** processed by the ultrasonic degassing system **102** may be transported to the midstream facility, without further processing.

The production fluid **110** exiting a well, prior to undergoing processing at the surface may be referred to as "raw" or "unprocessed" production fluid **110**. The production fluid **110** subjected to pre-processing of the upstream processing system **104** (e.g., prior to being subjected to degassing by the ultrasonic degassing system **102**) may be referred to as "pre-processed" production fluid **110**. The production fluid **110** subjected to the degassing of the ultrasonic degassing system **102** (e.g., the production fluid **110** from which the entrained gas has been separated and removed) may be referred to as "degassed" production fluid **110**. The production fluid **110** subjected to the post-processing of the downstream processing system **106** may be referred to as "processed" production fluid **110**.

In some embodiments, the processes controller **108** controls or monitors the processing of the production fluid **110**. For example, the process controller **108** may include a controller that controls and monitors upstream processing performed by the upstream processing system **104**, degassing performed by the ultrasonic degassing system **102**, or downstream processing performed by the downstream processing system **106**. In some embodiments, the process controller **150** includes a computer system similar to that of computer system **2000** described with regard to at least FIG. **12**.

FIG. **2** is a diagram that illustrates a cross-sectioned side view of an ultrasonic degassing unit **120** in accordance with one or more embodiments. In the illustrated embodiment, the ultrasonic degassing unit **120** includes a vessel **124** and an ultrasonic transducer system **126**. The vessel **124** includes a body **202** having an interior surface **204** and an exterior surface **206**, and an inlet **208** and an outlet **209**. In some embodiments, the inlet **208** is coupled to an outlet of an upstream system. For example, the inlet **208** may be coupled to an outlet of the upstream processing system **104**, and route pre-processed production fluid **110** from the upstream processing system **104**, into the interior **200** of the vessel **124**. As a further example, the inlet **208** may be coupled to an outlet of a production tree of a hydrocarbon well, and receive unprocessed production fluid **110** from the hydrocarbon well, such as a hydrocarbon fluid mixture of crude oil, water and natural gas. In some embodiments, the outlet **209** is coupled to an inlet of a downstream system. For example, the outlet **209** may be coupled to an inlet of the downstream processing system **106**, and route degassed production fluid **110** from the interior **200** of the vessel **124**, to the downstream processing system **106**. As a further example, the outlet **209** may be coupled to a midstream facility, such as a storage tank, a valve for loading the production fluid onto a transport vehicle, or a pipeline, and route the degassed production fluid **110** from the interior **200** of the vessel **124** to the midstream facility. In some embodiments, the vessel **124** is a pressure reduction apparatus that operates to reduce the pressure of the production fluid **110** to, for example, promote the separation of entrained gas from the production fluid **110**. For example, the vessel **124** may include a vapor recovery vessel (VRV), such as a vapor recover tower (VRT), in which the pressure of the production fluid **110** is rapidly reduced to flash gas from the production fluid **110**. The flash may occur in parallel with the introduction of ultrasonic signals **122** into the production fluid **110** (e.g., both occurring inside the vessel **124**) to promote the separation of the gas from the production fluid **110**.

The interior surface **204** of the body **202** of the vessel **124** may defines the interior region ("interior") **200** that defines a flowpath **212** of the production fluid **110**, through the vessel **124**. For example, the flowpath **212** may extend from the inlet **208**, through the interior **200**, to the outlet **209**. Fluid in the interior **200** of the vessel **124** may be considered to be in the flowpath **212**. In some embodiments, the vessel **124** includes an elongated body **202** having a longitudinal axis **214**, and some or all of the flowpath **212** runs generally parallel to the longitudinal axis **214** of the body **202**. For example, the vessel **124** may include a vapor recover tower (VRT) having a vertically oriented cylindrical body **202** having a vertically oriented longitudinal axis **214**, an inlet

208 at an upper end of the body 202, an outlet at a lower end of the body 202, and the flowpath 212 may extend from the inlet 208, through the interior 200, to the outlet 209, along a flowpath 212 generally parallel to the vertically oriented longitudinal axis 214. In some embodiments, the vapor recovery system 128 includes a conduit in fluid communication with an upper end or other portion of the interior 200 of the vessel 124 in which separated gas collects, and the vapor recovery system 128 removes the separated gas by way of the conduit.

In some embodiments, during operation, production fluid 110 enters the interior 200 of the vessel 124 by way of the inlet 208, travels through the interior of the vessel 124 along the flowpath 212, and eventually exits the interior 200 of the vessel 124 by way of the outlet 209. As the production fluid 110 travels along the flowpath 212, it may flow or otherwise be located around an ultrasonic transducer system 126 located in the flowpath 212, and be subjected to ultrasonic signals 122 generated by the ultrasonic transducer system 126. In some embodiments, a volume of the production fluid 110 is maintained in the interior 200 of the vessel 124, as indicated by the production fluid level 216. In some embodiments, the ultrasonic transducer system 126 is disposed below the production fluid level 216, to transmit the ultrasonic signals 122 into the volume of production fluid 110 below production fluid level 216. The duration for which production fluid 110 is held in the interior 200 of the vessel 124, and thus in the flowpath 212 and near the ultrasonic transducer system 126, may be controlled by controlling a flow rate of the production fluid 110 entering or exiting the vessel 124. For example, in an embodiment in which the production fluid 110 exits the vessel 124 at about the same rate as it enters the vessel 124, the flow rate of production fluid 110 may be increased to decrease the amount of time that the production fluid 110 is held in the interior 200 of the vessel 124, or be decreased to increase the amount of time that the production fluid 110 is held in the interior 200 of the vessel 124. Increasing the duration the production fluid 110 is held in the interior 200 of the vessel 124 may increase the exposure of the production fluid 110 to the ultrasonic signals 122 transmitted by the ultrasonic transducer system 126. In some embodiments, the flow rate is controlled to expose the production fluid 110 to ultrasonic signals for about 1-10 minutes (e.g., about 3-4 minutes on average), as it travels through the vessel 124.

In some embodiments, an ultrasonic transducer system 126 includes one or more ultrasonic transducer units 210. The one or more ultrasonic transducer units 210 may be operated to generate the ultrasonic signals 122 transmitted by ultrasonic transducer system 126. For example, the ultrasonic transducer system 126 of FIG. 2 may include one or more ultrasonic transducer units 210 that are operated to generate the ultrasonic signals 122 that are transmitted into the production fluid 110 as it travels through the interior 200 of the vessel 124, along the flowpath 212 and around the ultrasonic transducer system 126. In some embodiments, the one or more ultrasonic transducer units 210 are disposed in the interior 200 of the vessel 124. For example, one or more ultrasonic transducer units 210 may be disposed in the interior 200, below the production fluid level 216, such that they transmit the ultrasonic signals 122 into the volume of production fluid 110 below production fluid level 216.

In some embodiments, the ultrasonic transducer system 126 includes one or more ultrasonic transducer units 210 suspended in the interior 200 of the vessel 124, one or more ultrasonic transducer units 210 extending from the interior surface 204 of the vessel 124, or one or more ultrasonic transducer units 210 disposed on the exterior surface 206 of the vessel 124. FIG. 3 is a diagram that illustrates a cross-sectioned side view of an ultrasonic degassing unit 120 including an ultrasonic transducer system 126 that having ultrasonic transducer units 210 positioned in various locations accordance with one or more embodiments. In the illustrated embodiment, the ultrasonic transducer system 126 includes a first set of ultrasonic transducer units 302*a* suspended in the interior 200 of the vessel 124, in the flowpath 212 of the production fluid 110 and below the production fluid level 216. The first set of ultrasonic transducer units 302*a* may be suspended by a hanging element, such as a cable 304). The ultrasonic transducer system 126 also includes a second set of ultrasonic transducer units 302*b* disposed on and extending laterally from the interior surface 204 of the vessel 124, in the flowpath 212 of the production fluid 110 and below the production fluid level 216. The ultrasonic transducer system 126 further includes a third set of ultrasonic transducer units 302*c* disposed on the exterior surface 206 of the vessel 124, below the production fluid level 216. In such an embodiment, during operation, the ultrasonic transducer units 210 of the first and second ultrasonic transducer units 302*a* and 302*b* may transmit ultrasonic signals 122 directly into the production fluid 110 as it travels along the flowpath 212 and around the respective ultrasonic transducer units 210. Further, the ultrasonic transducer units 210 of the third set of ultrasonic transducer units 302*c* may transmit ultrasonic signals 122 through the wall of the body 202 of the vessel 124, into the production fluid 110 as it travels along the flowpath 212 and near the respective ultrasonic transducer units 210. Although the illustrated embodiment includes ultrasonic transducer units 210 suspended in the interior 200 of the vessel 124, disposed on and extending laterally from the interior surface 204 of the vessel 124, and disposed on the exterior surface 206 of the vessel 124, any combination of suitable positions and patterns of the ultrasonic transducer units 210 can be employed. Such embodiments may increase the number and coverage of the ultrasonic signals 122, thereby increasing the exposure of the production fluid 110 to the ultrasonic signals 122 and further promoting the separation of the entrained gas from the production fluid 110.

In some embodiments, the ultrasonic transducer system 126 includes a plurality of ultrasonic transducer units 210 disposed in a liner pattern about the vessel 124. For example, the plurality of ultrasonic transducer units 210 may be disposed along a length of an interior or exterior of the vessel 124 in a linear pattern, extending parallel to the longitudinal axis 214 of the vessel 124, as illustrated in FIG. 3. Although a single line is depicted for the purpose of illustration, the pattern may include a single line or multiple lines of ultrasonic transducer units 210. For example, the ultrasonic transducer units 210 may include four lines of ultrasonic transducer units 210 disposed on the interior surface 204 or the exterior surface 206, angularly offset by an angle of 90 degrees about the longitudinal axis 214.

In some embodiments, the ultrasonic transducer system 126 includes a plurality of ultrasonic transducer units 210 positioned in a non-linear pattern about the vessel 124. For example, the plurality of ultrasonic transducer units 210 may be positioned in a helical pattern defined by ultrasonic transducer units 210 disposed along a helical path, extending around the longitudinal axis of the vessel 124. FIG. 4 is a diagram that illustrates a side view of a set of ultrasonic transducer units 402 positioned in a helical pattern in accordance with one or more embodiments. In the illustrated embodiments, the ultrasonic transducer units 210 of the set of ultrasonic transducer units **402** are disposed along a helical path **404** spiraling around the longitudinal axis **214** and along a length of the interior surface **204** of the vessel **124**. In some embodiments, the helical path may extend a partial revolution, a complete revolution or multiple revolutions, around the longitudinal axis **214** of the vessel **124**. For example, an ultrasonic transducer system **126** may include eleven ultrasonic transducer unit **210**, each angularly offset by about 36 degrees from an adjacent ultrasonic transducer unit **210** and linearly offset by about 1 meter (m) from the adjacent ultrasonic transducer unit(s) **210**, such that the helical path **404** and pattern of ultrasonic transducer units **210** includes one complete turn about the longitudinal axis of the vessel **124**, and spans a distance of about 10 m along the length of the vessel **124**. Such patterning can be used to promote directional flow of the production fluid inside the vessel **124**. For example, the plurality of ultrasonic transducer units **210** disposed in a helical pattern about the vessel **124** may cause the production fluid **110** to spiral (or "roll") about the longitudinal axis **214** within the vessel **124**. The additional movement can further cause the different portions of the production fluid **110** to move toward and near the ultrasonic transducer units **210**, thereby increasing the exposure of the production fluid **110** to ultrasonic signals **122** and further promoting the separation of the entrained gas from the production fluid **110**. Although the illustrated embodiment depicts ultrasonic transducer units **210** disposed on the interior of the vessel **124** for the purpose of illustration, embodiments can include ultrasonic transducer units **210** suspended in a helical pattern, or disposed on the exterior surface **206** of the vessel **124** in a helical pattern.

In some embodiments, an ultrasonic transducer unit **210** includes one or more ultrasonic transducer heads. An ultrasonic transducer head may include an acoustic device that is operable to generate ultrasonic acoustic signals, such as ultrasonic signals **122**. FIG. **5** is a diagram that illustrates a cross-sectioned side view of an example ultrasonic transducer head **500** in accordance with one or more embodiments. In the illustrated embodiment, the transducer head **500** includes a body **502**, an acoustic signal source **504** and a nose (or "cover") **506**.

In some embodiments, the body **502** is a housing that at least partially encapsulates the acoustic signal source **504**, to protect and insulate the acoustic signal source **504**. For example, the body **502** may include an acoustic insulator having a metal outer casing and defining an interior region inside of which the acoustic signal source **504** is disposed. In some embodiments, the acoustic insulator of the body **502** inhibits ultrasonic signals **122** generated by the acoustic signal source **504** from passing through the body **502**, and, as a result, directs the ultrasonic signals **122** generated by the acoustic signal source **504** through the nose **506** (as indicated by arrow **508**).

In some embodiments, the acoustic signal source **504** includes a device that generates ultrasonic signals **122** in response to being driven by a corresponding source signal. For example, the acoustic signal source **504** may include a piezoelectric crystal. During operation, the piezoelectric crystal may be driven by an alternating current (AC) voltage of a given frequency, causing the piezoelectric crystal to generate acoustic signals of the given frequency. In some embodiments, the frequency of the AC voltage source signal is of a sufficient frequency to generate the ultrasonic signals **122**. For example, the frequency of the AC voltage source signal may be equal to or greater than about 20 kHz. In accordance with some embodiments, the source signal may include an AC voltage of a frequency in the range of about 20 kHz to about 40 kHz or in the range of about 23 kilohertz (kHz) to about 27 kHz, such as about 25 kHz, which causes the piezoelectric crystal to generate corresponding ultrasonic signals **122** having a frequency that corresponds to the source signal. In some embodiments, the ultrasonic transducer system **126** includes an ultrasonic source signal generator that generates the ultrasonic source signal used to drive the acoustic signal source **504** of the ultrasonic transducer head **500**. For example, the ultrasonic transducer system **126** may include an ultrasonic generator that includes an AC voltage source that can be controlled to generate an AC voltage having the desired ultrasonic frequency (e.g., about 20 kHz to about 40 kHz), and that is routed to the acoustic signal source **504** of the ultrasonic transducer head **500**.

In some embodiments, the nose **506** includes a protective cover disposed over the acoustic signal source **504** that encapsulates the acoustic signal source **504** in the body **502** and that is capable of transmitting ultrasonic signals **122** generated by the acoustic signal source **504**. For example, the nose **506** may be a metal or plastic cover disposed over the acoustic signal source **504** to enclose the acoustic signal source **504** in the body **502**. During operation, the ultrasonic signals **122** generated by the acoustic signal source **504** may be transmitted through the nose **506** and into the environment surrounding the ultrasonic transducer head **500**, in a transmission direction (as indicated by arrow **508**). A transmission surface **510** of an ultrasonic transducer head **500** may be defined as a surface on an exterior of the ultrasonic transducer head **500** from which the ultrasonic signals **122** generated by the ultrasonic transducer head **500** are transmitted. For example, the transmission surface **510** of the ultrasonic transducer head **500** may be the exterior surface of the nose **506**, from which the ultrasonic signals **122** are transmitted.

In some embodiments, an ultrasonic transducer unit **210** includes a housing and one or more ultrasonic transducer heads **500** disposed in the housing. During use, the housing may position the ultrasonic transducer heads **500** in close proximity to the production fluid **110**, while isolating the ultrasonic transducer heads **500** from the surrounding environment. Such a housing can be especially important for protecting transducer heads where the ultrasonic transducer unit **210** is exposed to harsh environmental conditions, such as being submersed in the production fluid **110**, or being exposed to the environment surrounding the vessel **124**.

FIG. **6** is a diagram that illustrates a cross-sectioned side view of an ultrasonic transducer unit **210** in accordance with one or more embodiments. In the illustrated embodiment, the ultrasonic transducer unit **210** includes a housing **600** and a plurality of ultrasonic transducer assemblies **601** disposed in an interior **602** of the housing **600**. In some embodiments, the housing **600** includes a hollow cylindrical tube, defining a cylindrically shaped interior **602**. In some embodiments, the housing **600** includes an access panel **603**. The access panel **603** may be installed (or "closed") to seal-off or otherwise isolate the interior **602** of the housing **600** and the ultrasonic transducer assemblies **601** from the surrounding environment. The access panel **603** may be uninstalled (or "opened") to provide access to the interior **602** of the housing **600**. This can provide access to the interior **602** of the housing **600** to, for example, install, reposition or remove the ultrasonic transducer assemblies **601** in the interior **602** of the housing **600**. In some embodiments, each of the ultrasonic transducer assemblies **601** includes one or more ultrasonic transducer heads **500**. The transmission surface **510** of each of the ultrasonic transducer heads **500** may abut an interior surface **604** of the housing **600**. During operation, the ultrasonic signals **122** generated by the ultrasonic transducer heads **500** may be transmitted from the transmission surface **510** of the ultrasonic transducer heads **500**, through an adjacent portion of the housing **600**, and into an adjacent portion of the environment surrounding the housing **600**.

In some embodiments, the ultrasonic transducer assemblies **601** are adhered to the interior surface **604** of the housing **600**. For example, the transmission surfaces **510** of the ultrasonic transducer heads **500** may be adhered to the interior surface **604** of the housing **600** using an adhesive, such as an epoxy adhesive. Such adhesion may provide acoustic coupling between the transmission surface **510** and the interior surface **604** of the housing **600** that facilitates the transmission of the ultrasonic signals **122** into and through the walls of the housing **600**. In some embodiments, the ultrasonic transducer heads **500** are biased against the interior surface **604** of the housing **600**. For example, each of the ultrasonic transducer assemblies **601** may include a biasing member positioned to exert a biasing force on the one or more ultrasonic transducer heads **500** of the ultrasonic transducer assembly **601**, to urge the transmission surface **510** of the one or more ultrasonic transducer heads **500** of the ultrasonic transducer assembly **601** into contact, or otherwise against, the interior surface **604** of the housing **600**. In some embodiments, the interface between the transmission surface **510** of the ultrasonic transducer head **500** and the interior surface **604** of the housing **600** is further adapted to facilitate the transmission of the ultrasonic signals **122**. For example, in the case where the transmission surface **510** of the ultrasonic transducer head **500** is not adhered to the interior surface **604** of the housing **600** using an adhesive, a transmission substance, such as a gel, may be disposed between the transmission surface **510** of the ultrasonic transducer head **500** and the interior surface **604** of the housing **600**, to further promote contact and acoustic coupling between the transmission surface **510** and the interior surface **604**.

In some embodiments, an ultrasonic transducer assembly **601** includes a plurality of ultrasonic transducer heads **500**. For example, an ultrasonic transducer assembly **601** may include a biasing member disposed between a pair of ultrasonic transducer heads **500**. The biasing member may provide an outward biasing force to urge the two ultrasonic transducer heads **500** outward, in opposite directions from one another. The biasing force may urge the respective transmission surfaces **510** of the pair of ultrasonic transducer heads **500** into contact with opposite portions of the interior surface **604** of the housing **600**. In such an embodiment, the ultrasonic transducer heads **500** may be operated to transmit ultrasonic signals **122** in opposite directions.

FIGS. **7**A and **7**B are diagrams that illustrate cross-sectioned side and end views, respectively, of an example an ultrasonic transducer unit **210** including ultrasonic transducer assemblies **601** that each include a plurality of ultrasonic transducer heads **500** in accordance with one or more embodiments. In the illustrated embodiment, each of the ultrasonic transducer assemblies **601** includes a biasing member **702** disposed between a pair of ultrasonic transducer heads **500**. The biasing member **702** may include a compressive spring, such as a compressive coil spring, a compressive rubber or urethane block spring, or the like. When the biasing member **702** is at least partially compressed, the biasing member **702** may provide outward biasing force (indicated by arrows **704**) that urges the two ultrasonic transducer heads **500** outward, in opposite directions from one another (in the direction of arrows **704**). In such an embodiment, the ultrasonic transducer heads **500** can be operated to transmit respective sets of ultrasonic signals **122** in opposite directions, through opposite portions of the housing **600**. The sets of ultrasonic signals **122** for an ultrasonic transducer assembly **601** may be generated in opposite directions, and parallel to an axis **705** of the transducer head assembly. When the ultrasonic transducer assembly **601** is installed in the interior **602** of the housing **600**, the biasing force may urge the respective transmission surfaces **510** of the ultrasonic transducer heads **500** in to contact with opposite portions of the interior surface **604** of the housing **600**. Such an embodiment may provide contact between each transmission surface **510** and the interior surface **604** of the housing **600**, to promote acoustic coupling between the transmission surface **510** and the interior surface **604** of the housing **600** that facilitates the transmission of the ultrasonic signals **122** into and through the housing **600**. In some embodiments, the biasing member **702** is employed without adhering the ultrasonic transducer head **500** to the interior surface **604** of the housing **600**. For example, the biasing member **702** may be positioned to exert a biasing force on the body **502** of the ultrasonic transducer head **500** to urge the transmission surface **510** of the ultrasonic transducer head **500** against the interior surface **604** of the housing **600**, without the use of an adhesive between the transmission surface **510** of the ultrasonic transducer head **500** and the interior surface **604** of the housing **600**. Such an embodiment may promote contact between the transmission surface **510** and the interior surface **604** of the housing **600** that provides acoustic coupling between the transmission surface **510** and the interior surface **604** of the housing **600** that facilitates the transmission of the ultrasonic signals **122** into and through the housing **600**, while enabling the transmission surface **510** to disengage from contact with the interior surface **604** of the housing **600** without having to break an adhesive bond between the transmission surface **510** and the interior surface **604** of the housing **600**. This can be particularly useful for installing, repositioning, or removing the ultrasonic transducer assemblies **601** and the ultrasonic transducer heads **500** in the housing **600**.

In some embodiments, the ultrasonic transducer assembly **601** can be adjusted between a retracted state and an expanded state. In the retracted state, the biasing member **702** may be compressed to reduce an overall height (H) of the ultrasonic transducer assembly **601**. The overall height (H) of the ultrasonic transducer assembly **601** may, for example, be less than a height (e.g., an interior diameter) of the interior **602** of the housing **600**. In such an embodiment, the ultrasonic transducer assembly **601** may be maintained in the retracted state while the ultrasonic transducer assembly **601** is moved into, out of, or within the interior **602** of the housing **600**. Once the ultrasonic transducer assembly **601** is located at an installation location within the interior **602** of the housing **600**, the biasing member **702** may be released or otherwise decompressed to place the ultrasonic transducer assembly **601** in the expanded state, which in turn biases the transmission surfaces **510** of the ultrasonic transducer assembly **601** into engagement with the respective portions of the interior surface **604** of the housing **600**, to secure the ultrasonic transducer assembly **601** in the installation location.

In some embodiments, the ultrasonic transducer assemblies **601** are installed in series along a length of the interior **602** of the housing **600**, linearly offset from one another by a given distance (D) (e.g., 0.25 meters (m)). In some embodiments, the plurality of ultrasonic transducer assemblies **601** have the same or different orientations. Such embodiments may increase the number and coverage of the ultrasonic signals **122**, thereby increasing the exposure of the production fluid **110** to the ultrasonic signals **122** and promoting the separation of the entrained gas from the production fluid **110** around the ultrasonic transducer unit **210**.

The ultrasonic transducer unit **210** of FIGS. **7**A and **7**B includes a plurality of ultrasonic transducer assemblies **601** having the same orientation in accordance with one or more embodiments. In the illustrated embodiment, the four ultrasonic transducer assemblies **601** are installed in series along a length of the interior **602** of the housing **600**, are linearly offset from one another by an offset distance (D) (e.g., 0.25 m), and are all arranged in the same orientation. In such an embodiment, the ultrasonic transducer assemblies **601** may generate respective sets of ultrasonic signals **122** in the same orientations, at locations offset from one another by the offset distance (D). For example, with each of the ultrasonic transducer assemblies **601** including "dual-opposing" ultrasonic transducer heads **500**, each of the ultrasonic transducer assemblies **601** may generate a first set of ultrasonic signals **122** in a first direction (as indicated by the upward ultrasonic signals **122** in FIGS. **7**A and **7**B, parallel to the axis **705**), and may generate a second set of ultrasonic signals **122** in a second direction, opposite from the first direction (e.g., angularly offset by 180 degrees from the first direction) (as indicated by the downward ultrasonic signals **122** in FIGS. **7**A and **7**B, parallel to the axis **705**).

FIGS. **8**A and **8**B are diagrams that illustrates cross-sectioned side and end views, respectively, of an ultrasonic transducer unit **210** including a plurality of ultrasonic transducer assemblies **601** (e.g., ultrasonic transducer assemblies **601***a*, **601***b*, **601***c* and **601***d*) having different orientations in accordance with one or more embodiments. In the illustrated embodiment, the four ultrasonic transducer assemblies **601***a*, **601***b*, **601***c* and **601***d* are installed in series along a length of the interior **602** of the housing **600**, are linearly offset from one another by an offset distance (D) (e.g., 0.25 m), and are arranged in different orientations. For example, in the illustrated embodiment each of the ultrasonic transducer assemblies **601***a*, **601***b*, **601***c* and **601***d* are oriented at an angular offset of about 90 degrees relative to an adjacent ultrasonic transducer assembly. For example, the axis **705** of each of the ultrasonic transducer assemblies **601***a* and **601***c* may have an orientation of 0 degrees, and the axis **705** of each of the ultrasonic transducer assembly **601***b* and **601***d* may have an orientation of 90 degrees. In such an embodiment, the ultrasonic transducer assemblies **601***a*, **601***b*, **601***c* and **601***d* may generate ultrasonic signals **122** in different orientations, at locations offset from one another by the offset distance (D). For example, with each of the ultrasonic transducer assemblies **601***a*, **601***b*, **601***c* and **601***d* including "dual-opposing" ultrasonic transducer heads **500**, the ultrasonic transducer assemblies **601***a* and **601***c* may each generate ultrasonic signals **122** in opposite directions along a first orientation, and the ultrasonic transducer assemblies **601***b* and **601***d* may each generate ultrasonic signals **122** in opposite directions along a second orientation offset from the first orientation by 90 degrees.

Although embodiments are described with regard to four ultrasonic transducer assemblies, a liner offset distance of about 0.25 m and angular offsets of about 90 degrees for the purpose of illustration, embodiments can include any suitable number of ultrasonic transducer assemblies **601**, other offset distances and other angular offsets. For example, an ultrasonic transducer unit **210** can include any number of ultrasonic transducer assemblies **601**, the ultrasonic transducer assemblies **601** can be linearly offset from one another by a suitable distance (e.g., in the range of about 0.1 m to 10 m), and can be angularly offset from one another by a suitable offset angle (e.g., in the range of about 1 degree to 180 degrees).

In some embodiments, an ultrasonic degassing system **102** includes elongated ultrasonic transducer units **210** that are oriented to protrude into the interior **200** of the vessel **124**, to intersect the production fluid **110** in the flowpath **212**. For example, an ultrasonic degassing system **102** may include one or more elongated ultrasonic transducer units **210** that protrude laterally or longitudinally into the interior of the vessel **124**, to intersect the production fluid **110** in the flowpath **212**. Such an embodiment may increase the number and coverage of the ultrasonic signals **122**, thereby increasing the exposure of the production fluid **110** to the ultrasonic signals **122** and promoting the separation of the entrained gas from the production fluid **110**.

FIG. **9**A is a diagram that illustrates an ultrasonic degassing system **102** including an ultrasonic transducer system **126** having two laterally oriented elongated ultrasonic transducer units **210** in accordance with one or more embodiments. An elongated ultrasonic transducer units **210** may have a body having a length that is greater than its width For example, an elongated ultrasonic transducer units **210** may have a cylindrical body having a length that is about 25% greater or more than its outer diameter. In the illustrated embodiment, the ultrasonic transducer units **210** protrude laterally into the interior of the vessel **124**, each having a longitudinal axis **902** extending perpendicular to the longitudinal axis **214** of the vessel **124** and the flowpath **212** of the production fluid **110**. During operation, the laterally oriented elongated ultrasonic transducer units **210** may intersect the production fluid **110** in the flowpath **212** in series, one after the other. In some embodiments, the laterally oriented elongated ultrasonic transducer units **210** are coupled to the side wall of the vessel **124**. For example, the elongated ultrasonic transducer units **210** may be installed through and fastened to an access hatch or port, such as a manway access, in the side wall of the vessel **124**. Although two laterally oriented elongated ultrasonic transducer units **210** are depicted for the purpose of illustration, any suitable number of laterally oriented elongated ultrasonic transducer units **210** may be employed (e.g., 1, 3, 4, 5 or more laterally oriented elongated ultrasonic transducer units **210** may be employed). In some embodiments, a laterally oriented elongated ultrasonic transducer unit **210** extends substantially across the width of the vessel **124**. For example, in the case of the vessel being a cylinder, a laterally oriented elongated ultrasonic transducer unit **210** may extend greater than about 40% (e.g., about 50%, 60%, 70%, 80% or 90%), or the entirety of, the internal diameter of the vessel **124**.

FIG. **9**B is a diagram that illustrates an ultrasonic degassing system **102** including an ultrasonic transducer system **126** having two longitudinally oriented elongated ultrasonic transducer units **210** in accordance with one or more embodiments. In the illustrated embodiment, the ultrasonic transducer units **210** protrude longitudinally into the interior of the vessel **124**, each having a longitudinal axis **902** extending parallel to the longitudinal axis **214** of the vessel **124** and the flowpath **212** of the production fluid **110**. During operation, the longitudinally oriented elongated ultrasonic transducer units **210** may intersect the production fluid **110** in the flowpath **212** in parallel. In some embodiments, the longitudinally oriented elongated ultrasonic transducer units

210 are coupled to an end cap of the vessel 124. For example, the elongated ultrasonic transducer units 210 may be installed through and fastened to an access hatch or port, such as a manway access, in a top end cap of the vessel 124. Although two longitudinally oriented elongated ultrasonic transducer units 210 are depicted for the purpose of illustration, any suitable number of longitudinally oriented elongated ultrasonic transducer units 210 may be employed (e.g., 1, 3, 4, 5 or more longitudinally oriented elongated ultrasonic transducer units 210 may be employed). In some embodiments, a longitudinally oriented elongated ultrasonic transducer unit 210 extends substantially across the length of the vessel 124. For example, in the case of the vessel being a cylinder, a longitudinally oriented elongated ultrasonic transducer unit 210 may extend greater than about 40% (e.g., about 50%, 60%, 70%, 80% or 90%), or the entirety of, the interior length of the vessel 124.

Embodiments of the ultrasonic degassing system 102 can be employed in a variety of context, including various locations within a hydrocarbon processing system. For example, the ultrasonic degassing system 102 may be employed in conjunction with a vapor recovery system (VRS) of the hydrocarbon processing system 100. In such an embodiment, the vessel 124 of the ultrasonic degassing system 102 may include a VRV. Further, in such an embodiment, one or more ultrasonic transducer units 210 may be positioned to transmit ultrasonic signals 122 into production fluid 110 traveling through the interior of the VRV. The ultrasonic signals 122 may cause the entrained gas to separate from the production fluid 110, and the separated gas may be captured and removed by the vapor recovery system 128. The recovered gas may, for example, be sold, flared off, or otherwise disposed of in a responsible and environmentally safe manner.

FIG. 10A is a diagram that illustrates an example ultrasonic degassing system 102 in accordance with one or more embodiments. In the illustrated embodiment, the ultrasonic degassing system 102 includes a vertically oriented vessel 124, and an ultrasonic transducer system 126 including a laterally oriented ultrasonic transducer unit 210. FIGS. 10B-10D are diagrams that illustrate perspective, cross-sectioned side and end views, respectively, of the ultrasonic transducer unit 210 of the ultrasonic degassing system 102 of FIG. 10A, in accordance with one or more embodiments.

The vertically oriented vessel 124 may be a vapor recover tower (VRT). In the illustrated embodiment, the vessel 124 includes an access hatch 1002 located in a side wall 1004 of the vessel 124. The access hatch 1002 is defined by an access hatch hole 1005 in the side wall 1004 of the vessel 124 that provide access to the interior 200 of the vessel 124, and an access hatch flange 1006. The access hatch 1002 may be, for example, an access manway that provides access to the interior 200 of the vessel 124. The access hatch flange 1006 includes mounting holes for use in bolting a complementary component, such as an access manway cover, to the access hatch flange 1006.

In the illustrated embodiment, the vessel 124 includes an inlet 208 located at an upper end 1010 of the vessel 124 and an outlet 209 located at a lower end 1012 of the vessel 124. The flowpath 212 may extend from the inlet 208 of the vessel 124 to the outlet 209 of the vessel 124. During operation, production fluid 110 may enter the vessel 124 by way of the inlet 208, travel downward in the interior 200 of the vessel 124, along the flowpath 212, and exit the vessel 124 by way of the outlet 209. A conduit 1013 of the vapor recovery system 128 may be in fluid communication with an upper end of the interior 200, and vapor recovery system 128 may remove the separated gas by way of the conduit 1013.

In the illustrated embodiment, the ultrasonic transducer unit 210 extends laterally, through the access hatch 1002, into the interior 200 of the vessel 124, such that the longitudinal axis 902 of the ultrasonic transducer unit 210 is perpendicular to the longitudinal axis 214 of the vessel 124. In such an embodiment, the ultrasonic transducer unit 210 laterally intersects the flowpath 212 of the production fluid 110 that is generally parallel to the longitudinal axis 214. The ultrasonic transducer unit 210 may be operated to generate ultrasonic signals 122 that are transmitted into the production fluid 110, as the production fluid 110 moves through the interior 200 of the vessel 124, along the flowpath 212, causing the entrained gas to separate from the production fluid 110.

In the illustrated embodiment, the housing 600 of the ultrasonic transducer unit 210 includes a hollow, cylindrically shaped tube, defining a cylindrically shaped interior 602. A trailing end 1022 of the housing 600 includes an access port 1023 and a transducer unit flange 1024. The transducer unit flange 1024 includes an outer set of mounting holes for use in securing the housing 600 to the vessel 124, and an inner set of mounting holes for use in securing the access panel 603 to the housing 600.

In the illustrated embodiment, the access panel 603 includes an electrical pass through 1030 and a purge port 1032. The electrical pass through 1230 may provide a conduit for the passage of an electrical wiring harness 1034 between the ultrasonic transducer assemblies disposed in the interior 200 of the housing 600, and an ultrasonic generator 1036 located external to the housing 600. The electrical pass through 1030 may include a sealed interface such that the interior 602 of the housing 600 is isolated from the surrounding environment, and can be maintained at a desired pressure. The purge port 1032 may provide a conduit for regulating pressure in the interior 602 of the housing 600 or introducing substances, such as nitrogen, into the interior 602 of the housing 600. A gasket 1033 may be disposed between the access panel 603 and the transducer unit flange 1024. The gasket 1033 may provide a fluid seal between the interior 602 of the housing 600 and the surrounding environment.

In the illustrated embodiment, the ultrasonic transducer unit 210 includes twelve ultrasonic transducer assemblies 601, each including dual-opposing ultrasonic transducer heads 500. The transmission surface 510 of each of the ultrasonic transducer heads 500 may have a shape that is complementary to the interior surface 604 of the housing 600. For example, the transmission surface 510 of each of the ultrasonic transducer heads 500 may have a curvature having a radius that is the same or similar to the radius of the interior surface 604 of the housing 600. In the illustrated embodiment, the body 502 of each of the ultrasonic transducer heads 500 includes a stem 1038 and a shoulder 1040. Further, the biasing member 702 of each of the ultrasonic transducer assemblies 601 includes a spring that is disposed around the stems 1038 of the pair of ultrasonic transducer heads 500 of the ultrasonic transducer assembly 601, with opposite ends of the spring engaging the shoulders 1040 of the bodies 502 of the pair of ultrasonic transducer heads 500 of the ultrasonic transducer assembly 601. The stem 1038 may help to secure the spring in position, and guide movement of the bodies 502 and the spring during retraction and expansion of the ultrasonic transducer assembly 601. In the illustrated embodiment, each of the twelve ultrasonic transducer assemblies 601 are linearly offset by an offset distance

(D) (e.g., about 0.25 m) and an angular offset of about 90 degrees. Each of the ultrasonic transducer assemblies **601** may be electrically coupled to the ultrasonic generator **1036** by way of the electrical wiring harness **1034**.

Assembly of the ultrasonic transducer unit **210** may include the following: removing the access panel **603** from the housing **600**; positioning each of the twelve ultrasonic transducer assemblies **601** into their respective positions within the interior **602** of the housing **600**; passing the electrical wiring harness **1034** through the electrical pass through **1030** of the access panel **603**; fastening bolts through the mounting holes of the access panel **603** and the inner set of mounting holes of the transducer unit flange **1024** to secure the access panel **603** to the housing **600** and to seal-off the interior **602** of the housing **600** from the surrounding environment; and injecting gas, such as nitrogen, into the interior **602** of the housing **600** by way of the purge port **1032** to pressurize the interior **602** of the housing **600** to a pressure above the operating pressure at the interior **200** the vessel **134**. Such a pressurization may inhibit substances, such as production fluid **110**, from entering the interior **602** of the housing **600** during use. The positioning of each of the twelve ultrasonic transducer assemblies **601** into their respective positions within the interior **602** of the housing **600** may include, for each of the twelve ultrasonic transducer assemblies **601** performing the following: attaching the ultrasonic transducer assembly **601** to the electrical wiring harness **1034**; compressing the ultrasonic transducer assembly **601** into a retracted state such the height of the ultrasonic transducer assembly **601** is less than the diameter of the interior **602** of the housing **600**; moving the ultrasonic transducer assembly **601** longitudinally along the interior **602** of the housing **600**, into position within the interior **602** of the housing **600**; releasing or otherwise de-compressing the ultrasonic transducer assembly **601**, to move the ultrasonic transducer assembly **601** into an expanded state such the transmission surfaces **510** of the ultrasonic transducer assembly **601** engage corresponding portions of the interior surface **604** of the housing **600**. Disassembly of the ultrasonic transducer unit **210** may be the reverse of that described for assembly.

Assembly of the ultrasonic transducer unit **210** into the vessel **134** may include the following: inserting a leading end **1020** of the housing **600** into and through the access hatch **1002** and into the interior **200** of the vessel **124**; and fastening bolts through the outer set of mounting holes of the transducer unit flange **1024** of the housing **600** and the complementary mounting holes of the access hatch flange **1006** of the access hatch **1002** of the vessel **124**, to secure the housing **600** to the vessel **124**. Disassembly of the ultrasonic degassing unit **120** from the vessel **134** may be the reverse of that described for assembly. Assembly of ultrasonic transducer unit **210** may be performed before, after or during assembly of the ultrasonic transducer unit **210** into the vessel **134**.

Such a modular configuration can provide flexibility in the installation and maintenance of the ultrasonic degassing system **102**. For example, the housing **600** may be secured to the vessel **124**, and assembly of the ultrasonic transducer unit **210** can take place with the housing **600** already secured to the vessel **124**. As a further example, the ultrasonic transducer assemblies **601** can be accessed for maintenance or replacement by simply removing the access panel **603** of the housing **600**, without having to remove the housing **600** from the vessel **124**. This may allow the vessel **124** to remain in a sealed state, with minimal or no interruption of the flow of the production fluid **110** through the vessel **124**, during installation, inspection, replacement, repositioning or removal of the ultrasonic transducer assemblies **601**.

Operation of the ultrasonic degassing system **102** can include providing a flow of the production fluid **110** through the inlet **208** of the vessel **124**, and operating the ultrasonic transducer unit **210** to transmit the ultrasonic signals **122**. In some embodiments, operating the ultrasonic transducer unit **210** includes operating the ultrasonic generator **1036** to supply a voltage of a desired ultrasonic frequency (e.g., 25 kHz), to the ultrasonic transducer assemblies **601**, which in turn causes the transducer heads **500** of the ultrasonic transducer assemblies **601** to generate the ultrasonic signals **122** that are transmitted through the housing **600** and into the production fluid **110** surrounding the housing **600**. As the production fluid **110** flows from the inlet **208** of the vessel **124** to the outlet **209** of the vessel **134**, along the flowpath **212**, the ultrasonic signals **122** generated by the ultrasonic transducer unit **210** may be transmitted into the production fluid **110** surrounding the ultrasonic transducer unit **210**, causing the entrained gas to separate from the production fluid **110** and rise to the upper end **1010** of the interior **200** of the vessel **124**, where it can be collected and disposed of by a vapor recovery system (e.g., vapor recovery system **128**). The degassed production fluid **110** may flow to the lower end **1012** of the vessel **124**, and exit the vessel **124** by way of the outlet **209**.

FIG. **11** is a flowchart that illustrates a method **1100** of degassing hydrocarbon production fluid in accordance with one or more embodiments. The method **1100** may include providing an ultrasonic degassing system (block **1102**). In some embodiments, providing an ultrasonic degassing system includes providing an ultrasonic degassing system similar to that of the ultrasonic degassing system **102**. For example, providing an ultrasonic degassing system may include assembling or otherwise providing the hydrocarbon processing system **100**, including the ultrasonic degassing system **102**. The ultrasonic degassing system **102** may include one or more ultrasonic degassing units **120**, each including a vessel **124** and an ultrasonic transducer system **126**. Each of the ultrasonic transducer system **126** may include one or more ultrasonic transducer units **210**, each including one or more ultrasonic transducer heads **500**, as described here.

The method **300** may include conducting pre-processing of the hydrocarbon production fluid (block **1104**). In some embodiments, conducting pre-processing of hydrocarbon production fluid includes the upstream processing system **104** processing raw/unprocessed production fluid **110** to generate pre-processed production fluid **110** for processing by the ultrasonic degassing system **102**. For example, the upstream processing system **104** may include a water separator system, a heater treater system or a pressure reduction system. The water separator system may operate to separate and remove some or all of water contained in the production fluid **110**, from the production fluid **110**. The heater treater system may operate to heat the production fluid **110** to promote the separation of entrained gas from the production fluid **110**. The pressure reduction system may operate to reduce the pressure of the production fluid **110** to, for example, promote the separation of entrained gas from the production fluid **110**.

The method **300** may include operating the ultrasonic degassing system to separate entrained gas from the hydrocarbon production fluid (block **1106**). In some embodiments, operating the ultrasonic degassing system to separate entrained gas from hydrocarbon production fluid includes providing a flow of production fluid **110** (e.g., raw or pre-processed production fluid **110**) through the ultrasonic degassing system **102**, and operating the ultrasonic degassing system **102** to transmit ultrasonic signals **122** into the production fluid **110** to cause entrained gas of the production fluid **110** to separate from the production fluid **110**. Continuing with the above example, operating the ultrasonic degassing system to separate entrained gas from hydrocarbon production fluid may include introducing production fluid **110** through an inlet **208** of the vessel **124** such that it flows along the flowpath **212**, to an outlet **209** of the vessel **124**, and controlling an ultrasonic generator (e.g., ultrasonic generator **1036**) to generate source signals that drive the one or more ultrasonic transducer heads **500** to generate ultrasonic signals **122** that are transmitted into the production fluid **110** as it flows around the one or more ultrasonic transducer units **210**, as described here. In some embodiments, the source signal may include an AC voltage of a frequency in the range of about 20 kHz to 40 kHz, such as about 25 kHz, which causes the ultrasonic transducer heads **500** to generate corresponding ultrasonic signals **122** having a frequency of about 20 kHz to 40 kHz, such as about 25 kHz. In some embodiments, the gas separated from the production fluid **110** is removed by the vapor recovery system **128**. The recovered gas may, for example, be sold, flared-off, or otherwise disposed of in a responsible and environmentally safe manner.

The method **300** may include conducting post-processing of the hydrocarbon production fluid (block **1108**). In some embodiments, conducting post-processing of hydrocarbon production fluid includes the downstream processing system **106** processing degassed production fluid **110** to generate processed production fluid **110**. For example, the downstream processing system **106** may include a water separator system, a heater treater system or a pressure reduction system. The water separator system may operate to separate and remove some or all of water contained in the production fluid **110**, from the production fluid **110**. The heater treater system may operate to heat the production fluid **110** to promote the separation of entrained gas from the production fluid **110**. The pressure reduction system may operate to reduce the pressure of the production fluid **110** to, for example, promote the separation of entrained gas from the production fluid **110**.

In some embodiments, operation of the ultrasonic degassing system **102** or other components of the hydrocarbon processing system **100** are controlled by the process controller **150**. For example, the process controller **150** may control and monitor the flowrate of production fluid **110** into and through the vessel **134**, may control and monitor operation of the ultrasonic generator **1036**, or may monitor and control operation of the vapor recovery system **128**, the upstream processing system **104**, or the downstream processing system **106**.

FIG. **12** is a diagram that illustrates an example computer system (or "system") **2000** in accordance with one or more embodiments. In some embodiments, the system **2000** is a programmable logic controller (PLC). The system **2000** may include a memory **2004**, a processor **2006** and an input/output (I/O) interface **2008**. The memory **2004** may include non-volatile memory (e.g., flash memory, read-only memory (ROM), programmable read-only memory (PROM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM)), volatile memory (e.g., random access memory (RAM), static random access memory (SRAM), synchronous dynamic RAM (SDRAM)), or bulk storage memory (for example, CD-ROM or DVD-ROM, hard drives). The memory **2004** may include a non-transitory computer-readable storage medium having program instructions **2010** stored thereon. The program instructions **2010** may include program modules **2012** that are executable by a processor (e.g., the processor **2006**) to cause the functional operations described, such as those described with regard to operation of the processing system **100**, including the ultrasonic degassing system **102**, and method **1100**.

The processor **2006** may be any suitable processor capable of executing program instructions. The processor **2006** may include a central processing unit (CPU) that carries out program instructions (e.g., the program instructions of the program modules **2012**) to perform the arithmetical, logical, or I/O operations described. The processor **2006** may include one or more processors. The I/O interface **2008** may provide an interface for communication with one or more I/O devices **2014**, such as a computer mouse, a keyboard, or a display screen (e.g., an electronic display for displaying a graphical user interface (GUI)). The I/O devices **2014** may include one or more of the user input devices. The I/O devices **2014** may be connected to the I/O interface **2008** by way of a wired connection (e.g., an Industrial Ethernet connection) or a wireless connection (e.g., a Wi-Fi connection). The I/O interface **2008** may provide an interface for communication with one or more external devices **2016**, such as an ultrasonic source signal generator, sensors, valves, pumps, motors, or other computers and networks.

Further modifications and alternative embodiments of various aspects of the disclosure will be apparent to those skilled in the art in view of this description. Accordingly, this description is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the general manner of carrying out the embodiments. It is to be understood that the forms of the embodiments shown and described herein are to be taken as examples of embodiments. Elements and materials may be substituted for those illustrated and described herein, parts and processes may be reversed or omitted, and certain features of the embodiments may be utilized independently, all as would be apparent to one skilled in the art after having the benefit of this description of the embodiments. Changes may be made in the elements described herein without departing from the spirit and scope of the embodiments as described in the following claims. Headings used herein are for organizational purposes only and are not meant to be used to limit the scope of the description.

It will be appreciated that the processes and methods described herein are example embodiments of processes and methods that may be employed in accordance with the techniques described herein. The processes and methods may be modified to facilitate variations of their implementation and use. The order of the processes and methods and the operations provided may be changed, and various elements may be added, reordered, combined, omitted or modified. Portions of the processes and methods may be implemented in software or hardware, or a combination thereof. For example, some or all of the portions of the processes and methods may be implemented by a computer system.

As used throughout this application, the word "may" is used in a permissive sense (i.e., meaning having the potential to), rather than the mandatory sense (i.e., meaning must). The words "include," "including," and "includes" mean including, but not limited to. As used throughout this application, the singular forms "a", "an," and "the" include plural referents unless the content clearly indicates otherwise. Thus, for example, reference to "an element" may include a combination of two or more elements. As used throughout this application, the term "or" is used in an inclusive sense, unless the content clearly indicates otherwise. That is, a description of an element including A or B may refer to the element including one or both of A and B. As used throughout this application, the phrase "based on" does not limit the associated operation to being solely based on a particular item, unless the content clearly indicates otherwise. Thus, for example, processing "based on" data A may include processing based at least in part on data A and based at least in part on data B. As used throughout this application, the term "from" does not limit the associated operation to being directly from, unless the content clearly indicates otherwise. Thus, for example, receiving an item "from" an entity may include receiving an item directly from the entity or indirectly from the entity (e.g., by way of an intermediary entity). Unless specifically stated otherwise, as apparent from the discussion, it is appreciated that throughout this specification discussions utilizing terms such as "processing," "computing," "calculating," "determining" or the like refer to actions or processes of a specific apparatus, such as a special purpose computer or a similar special purpose electronic processing/computing device. In the context of this specification, a special purpose computer or a similar special purpose electronic processing/computing device is capable of manipulating or transforming signals, typically represented as physical, electronic or magnetic quantities within memories, registers, or other information storage devices, transmission devices, or display devices of the special purpose computer or similar special purpose electronic processing/computing device.

What is claimed is:

1. A hydrocarbon fluid processing system comprising:

an ultrasonic hydrocarbon degassing unit comprising:

a vertically oriented vapor recovery vessel configured to direct flow of a hydrocarbon fluid mixture along a flowpath that extends through an interior of the vertically oriented vapor recovery vessel, from an upper end of the vertically oriented vapor recovery vessel to a lower end of the vertically oriented vapor recovery vessel, the hydrocarbon fluid mixture comprising a hydrocarbon liquid, a gas entrained in the hydrocarbon liquid, and water; and

an ultrasonic transducer system comprising an ultrasonic transducer unit disposed on a exterior surface of the vertically oriented vapor recovery vessel and along the flowpath of the hydrocarbon fluid mixture such that the hydrocarbon fluid mixture is configured to flow by the ultrasonic transducer unit while passing through the vertically oriented vapor recovery vessel, the ultrasonic transducer unit configured to transmit ultrasonic signals into the hydrocarbon fluid mixture as the hydrocarbon fluid mixture flows by the ultrasonic transducer unit, and the ultrasonic signals configured to separate the gas from the hydrocarbon liquid; and

a water separating system configured to remove the water from the hydrocarbon fluid mixture, wherein the ultrasonic hydrocarbon degassing unit is located downstream of the water separating system such that the ultrasonic signals are transmitted into the hydrocarbon fluid mixture by the ultrasonic hydrocarbon degassing unit after the water is removed from the hydrocarbon fluid mixture by the water separating system.

2. The system of claim **1**, wherein the ultrasonic signals comprise acoustic signals having a frequency in a range of 23 kilohertz (kHz) to 27 kHz.

3. The system of claim **2**, wherein the ultrasonic signals comprise acoustic signals having a frequency of 25 kilohertz (kHz).

4. The system of claim **1**, wherein the vertically oriented vapor recovery vessel comprises a vapor recover tower.

5. The system of claim **1**, wherein the hydrocarbon fluid processing system further comprises a vapor recovery system coupled to the vertically oriented vapor recovery vessel, the vapor recovery system configured to remove the gas separated from the hydrocarbon liquid.

6. The system of claim **5**, wherein the vertically oriented vapor recovery vessel comprises a low pressure chamber configured to collect the gas separated from the hydrocarbon liquid at the upper end of the vertically oriented vapor recovery vessel, and wherein the vapor recovery system is configured to remove the gas separated from the hydrocarbon liquid from the upper end of the vertically oriented vapor recovery vessel.

7. The system of claim **1**, wherein the ultrasonic transducer unit comprises a plurality of ultrasonic transducer heads.

8. The system of claim **1**, wherein the ultrasonic transducer unit is coupled to a wall of the vertically oriented vapor recovery vessel.

9. The system of claim **8**, wherein the ultrasonic transducer unit extends laterally along the exterior surface of the vertically oriented vapor recovery vessel, in an orientation perpendicular to a longitudinal axis of the vertically oriented vapor recovery vessel.

10. The system of claim **1**, wherein the ultrasonic transducer unit is coupled to an end cap of the vertically oriented vapor recovery vessel.

11. The system of claim **10**, wherein the ultrasonic transducer unit extends longitudinally along the exterior surface of the vertically oriented vapor recovery vessel, in an orientation parallel to a longitudinal axis of the vertically oriented vapor recovery vessel.

12. The system of claim **1**, wherein the ultrasonic transducer system comprises a plurality of ultrasonic transducer units disposed along a length of the vertically oriented vapor recovery vessel.

13. The system of claim **1**, wherein the ultrasonic transducer unit comprises a first plurality of ultrasonic transducer heads disposed in series along a first axis perpendicular to the flowpath, and configured to transmit a first subset of the ultrasonic signals into the hydrocarbon fluid mixture as the hydrocarbon fluid mixture flows along the flowpath, and wherein the ultrasonic transducer system further comprises: a second ultrasonic transducer unit comprising a second plurality of ultrasonic transducer heads disposed in series along a second axis perpendicular to the flowpath, and configured to transmit a second subset of the ultrasonic signals into the hydrocarbon fluid mixture as the hydrocarbon fluid mixture flows along the flowpath, wherein the first axis is located above the second axis such that the first subset of the ultrasonic signals is transmitted into the hydrocarbon fluid mixture upstream of the second subset of the ultrasonic signals being transmitted into the hydrocarbon fluid mixture.

14. A hydrocarbon fluid processing system comprising:

an ultrasonic hydrocarbon degassing unit comprising:

a vapor recovery vessel configured to direct flow of a hydrocarbon fluid mixture along a flowpath that extends through an interior of the vapor recovery vessel, the hydrocarbon fluid mixture comprising a hydrocarbon liquid and a gas entrained in the hydrocarbon liquid; and an ultrasonic transducer system comprising an ultrasonic transducer unit disposed on an exterior surface of the vapor recovery vessel and along the flowpath of the hydrocarbon fluid mixture such that the hydrocarbon fluid mixture is configured to flow by the ultrasonic transducer unit, the ultrasonic transducer unit configured to transmit ultrasonic signals into the hydrocarbon fluid mixture by the ultrasonic transducer unit, and the ultrasonic signals configured to separate the gas from the hydrocarbon liquid; and

a vapor recovery system coupled to the vapor recovery vessel, the vapor recovery system configured to remove the qas separated from the hydrocarbon liquid.

15. The system of claim **14**, wherein the ultrasonic signals comprises acoustic signals having a frequency in a range of 23 kilohertz (kHz) to 27 kHz.

16. The system of claim **14**, wherein the hydrocarbon fluid mixture comprises water, wherein the hydrocarbon fluid processing system further comprises a water separating system configured to remove the water from the hydrocarbon fluid mixture, and wherein the ultrasonic hydrocarbon degassing unit is located downstream of the water separating system such that the ultrasonic signals are transmitted into the hydrocarbon fluid mixture by the ultrasonic hydrocarbon degassing unit after the water is removed from the hydrocarbon fluid mixture by the water separating system.

17. The system of claim **14**, wherein the vapor recovery vessel comprises a vapor recover tower.

18. A hydrocarbon fluid processing system comprising:

an ultrasonic hydrocarbon degassing unit comprising:

a vertically oriented vapor recovery vessel configured to direct flow of a hydrocarbon fluid mixture along a flowpath that extends through an interior of the vertically oriented vapor recovery vessel, from an upper end of the vertically oriented vapor recovery vessel to a lower end of the vertically oriented vapor recovery vessel, the hydrocarbon fluid mixture comprising a hydrocarbon liquid and a gas entrained in the hydrocarbon liquid; and

an ultrasonic transducer system comprising an ultrasonic transducer unit disposed on an exterior surface of the vertically oriented vapor recovery vessel and along the flowpath of the hydrocarbon fluid mixture such that the hydrocarbon fluid mixture is configured to flow by the ultrasonic transducer unit while passing through the vertically oriented vapor recovery vessel, the ultrasonic transducer unit configured to transmit ultrasonic signals into the hydrocarbon fluid mixture as the hydrocarbon fluid mixture flows by the ultrasonic transducer unit, and the ultrasonic signals configured to separate the gas from the hydrocarbon liquid;

wherein the vertically oriented vapor recovery vessel comprises a low pressure chamber configured to collect the gas separated from the hydrocarbon liquid at the upper end of the vertically oriented vapor recovery vessel, and a vapor recovery system is configured to remove the gas separated from the hydrocarbon liquid from the upper end of the vertically oriented vapor recovery vessel.

* * * * *